Street Network Centrality and Built Form Evolution in the Spatial Development of London's Periphery 1880-2013

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Submitted for the degree of Doctor of Philosophy

August 2014

I, Ashley Dhanani confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Signature……………………………………

Statement of Conjoint Work

This work was carried out with a funded studentship as part of the Adaptable Suburbs EPSRC funded research project at UCL (EPSRC reference: EP/I001212/1), which the author worked on from 1st November 2010 to 31st December 2013. The EPSRC project was a study of the relationship between networks of human activity and the changing form of urban and suburban centres through time, focusing on four outer-London suburbs and building on an earlier research project into London's suburbs.

The thesis is built on the data collected for the project by the project team. Under the guidance of his PhD supervisors, the author had primary responsibility for developing the GIS-based space syntax methods, cartographic redrawing and built form capture for the project. The author's work is distinct from the project. Its focus is research into the large-scale network and built form development of Greater London over time. The work contained within this thesis is entirely the author's own; including the data structuring, analysis and background research.

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Acknowledgements

I would firstly like to thank and acknowledge Professor Laura Vaughan and Dr Claire Ellul, my primary and secondary supervisors. I am immensely grateful for their unending patience, time and support throughout my PhD studies.

I would also like to thank and acknowledge the rest of the Adaptable Suburbs research team that I have worked with for the last three and half years: Sam Griffiths, Muki Haklay, Victor Buchli, Patrick Rickles and David Jeevendrampillai. Working in collaboration with all those involved in the Adaptable Suburbs research team has undoubtedly improved the quality of my research, understanding of other subject areas and interdisciplinary working.

Finally, I would like to thank the EPSRC that provided the funding for the Adaptable Suburbs research project and my PhD research.

Abstract

This thesis presents a street network and built form analysis of the urbanisation of four peripheral areas of London as they transformed from satellite settlements to parts of the continuous urban fabric of London over 130 years. The analysis is carried out by applying and combining space syntax and GIS techniques to chart the changing structures of network centrality through time, and how this relates to the built form, as they co-evolved. Through these methods an understanding of the factors that have contributed to the current spatial form of the case studies is developed. In taking an historical view of the urbanisation of the fringes of the London this thesis unpacks the spatial characteristics of areas characterised as 'suburban', revealing the specific spatial and architectural forms they have developed.

It is shown that peripheral areas cannot be characterised as generically suburban and great variation exists within this simplistic categorisation. The development of transport infrastructures based around motor vehicles are shown to be reflected in the transformation of built form, both at the household and community level, illustrating the interdependence of technological development, regional planning regimes and every-day life. Large-scale transport infrastructures that operate at a regional level are shown to have local impacts whilst local changes are shown to have cumulative effects that transform the spatial character of large areas. The analysis of the historical patterns and stages of urbanisation allow new insights into the contemporary city to be developed that are explicitly aware of the role of historical processes in shaping the spaces of the contemporary city and the environments that we experience today. It also enables questions about future adaptability to be approached with a better understanding of the emergence and evolution of peri-urban areas.

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1 Introduction

The aim of this research is to contribute to the understanding of how peripheral areas of London, and peri-urban areas more generally, have successfully persisted and adapted over 130 years to arrive at their current spatial and architectural forms. Developing an understanding of the concepts and realities of adaptability and persistence of the built environment is crucial in understanding the future development potentials of urban areas. In 2008, for the first time in human history more than half of the world's population lived in urban areas (United Nations, 2008). The combination of an ever-increasing world population and the increasing urbanisation of that population, especially in peripheral areas (Clapson and Hutchinson, 2010), makes the role of cities and the relationship between the city and its inhabitants more important than ever. Only by understanding how cities have changed to accommodate new spatial and social realities will current and future urban planning and policy be able to ensure the continued vitality of urban areas. This is only achievable by ensuring policies do not preclude certain future uses, and are mindful of the necessity of change within the spatial and architectural forms of the city (Vaughan et al., 2009).

This is particularly important in areas on the periphery of the city, in both its spatial and socio-economic dimensions, that are often poorly defined leading to a sclerosis of approaches to understanding them and creating coherent policies in relation to them (Vaughan et al., 2009). The periphery of urban areas have been the centre for divergent discourses within academic studies and representations within popular culture, ranging from the utopian to the dystopian (Vaughan et al. 2009, 2010). Previous studies have illustrated that this discourse is very much situated in the present, rather than taking a historical view of what the peri-urban, or suburban is in relation to the city. This ignores the complex processes that occur in suburban areas, and their dynamic relationship with the rest of the city (Griffiths et al. 2010, Vaughan, 2011). The suburban is an urban typology that is not universal or fixed and may be more appropriate to assess in the context of a peri-urban area, that might be considered to be suburban, based on a gradient of urban-ness, taking into account their local and city-scale relationships. Space syntax and land use analysis has shown that at different scales the roads that are the most central within a network configuration vary, as do the land uses associated with them. This indicates that different functional qualities are expressed morphologically, and that suburban centres are not a monoculture, but potentially express the same scaling properties, or pervasive centrality, as the urban whole, on a smaller scale (Vaughan et al., 2010). Peri-urban areas are some of the most contested areas of the city, and also the locations where there is significant potential and capacity for change (Stanilov, 2004). Therefore a deeper understanding of their development will usefully inform debate and policy about these spatial and social frontiers of urban development. It is this urban landscape, within the context of London, that this research focuses on. Historically, many parts of London that are now considered to form the central areas were what would now be called suburban, highlighting the importance of peri-urban research in understanding the urban growth process. In order to inform debate about urban development this research focuses on the changes that occur in the spatial and architectural ordering of the city, as well as the stable elements across time. The aim of this is to understand the peri-urban as a relational entity that changes and persists through time, and forms an intrinsic part of the city and its growth processes. Suburban development can be considered as part of a wider process of peri-urban expansion that is occurring globally (Stanilov, 2004), giving this research area particular value in understanding potential urban futures in a global context. Understanding the ways in which urban areas develop and change is vital in assessing the driving forces behind their development, while aspects of urban areas that are persistent over time will reveal the underlying nature of the urban fabric and the requirements of human settlement that are constants.

This research focuses on the evolution of the street network, and the built form of four areas of peri-urban London. Through an analysis of the changing configurations of the street network and the composition of the built form, their spatial and architectural evolution is charted and analysed, developing an understanding of the relationship between the spatial structure and built environment of London's urban expansion over the past 130 years. The spatial analysis is centred on the usage of space syntax network analysis tools, that are used to decode the structure of the city through an understanding of the influence of urban spatial structure on the lived experience of the city (Hillier and Hanson, 1984; Hiller, 1996). Space syntax analysis tools and theories enable a reading of the configuration of the street network that accounts for the structuring of potentials for specific forms of mobilities and flows within particular locations in the network. The analysis identifies commonalities and differences in the developmental trajectory and stages of urbanisation in the peri-urban centres. These commonalities and differences are central to evaluating the process of urbanisation of the fringes of London, as they will reveal the generic as well as particular processes of urbanisation that they have undergone. The utilisation of the theories and methods of space syntax approaches to urban network analysis enables the combination of mathematical modelling of the changing potentials for movement in the urban form of London, and an understanding of how the structures of movement potentials in the city are formed by, and inform social relations within space (Hillier, 1996). These potentials for movement can be seen as akin to the affordance, as described by Gibson (1977), of possibilities of co-presence (Urry, 2007) that lie at the heart of the theorised movement economy (Hillier, 1996). Technological development is considered to be a key driver for mobilities in the city (Jackson, 1978; Clapson, 2001; Levinson, 2008) and thus movement economy. This analysis, whilst not explicitly examining the role of technology in the development of urban areas, is able to assess the impacts of technological change through the analysis of the forms of network infrastructures that develop over time and the changing built forms that populate the network. The importance of movement to the function of cities relies on the interaction between the inhabitants of urban areas and the way they move within it. Understanding the spatial and architectural methods through which this develops is key to understanding the changing technologies, through which people engage with, and are engaged by urban space. By combining mathematical and social understandings of the city network structure and built form development, a rich and meaningful analysis of urban society-space networks and their development over time can be created.

The primary question that this work addresses is; how does network centrality and structure change, and architectural form develop over time, as semi-rural areas transform to more urban states? Through the spatial historical analytical approach taken, the research aims to shed new light on the peri-urban development of London, allowing greater general understanding of the development processes that occur on the urban periphery. Although this research is focussed on London's periphery, the findings can be used to inform understandings of peri-urban areas more generally. Furthermore how the street network adapts over time to accommodate an increasing population and a greater mass of built forms will enable important insights into the nature of urban development. This can contribute to a general understanding of the ways in which greater built densities and populations can be successfully accommodated in urban space, something that is currently a global concern.

This research also seeks to address the problem of the lack of detailed understanding of the processes of peri-urban development at both local and sub-regional scales from a morphological perspective. This is particularly in relation to the morphological aspects of the development of street networks and the architectural forms that develop over time (Whitehand, 2001). This research aims to reconcile the necessity for highly detailed spatial data with the necessity for the analysis of large areas to create a full understanding of the processes of urban development. This is achieved through the combination of Geographic Information Science (GIS) and morphological research methods. The second area that this research addresses is the methodological approaches to such research, by rigorously bringing together, and reconciling GIS and morphological research methods. This is achieved by evaluating the data sources and network representations that are used in space syntax, urban morphological research and GIS research domains, and secondly through the application of novel GIS-based methods to capture highly detailed and large scale historic data sets of built forms and street networks that can then be analysed using the principals of architectural morphological research practices. Finally the analysis stage brings together GIS based analysis and traditional morphological approaches to analysis.

This research stems from the Engineering and Physical Sciences Research Council (EPSRC) funded Adaptable Suburbs project at the Bartlett School of Graduate Studies (Adaptable Suburbs, 2010-2014). This is a study of the relationship between networks of human activity and the changing form of urban and suburban centres through time. The Adaptable Suburbs project followed on from the University College London (UCL) *Towards Successful Suburban Town Centres* (SSTC, 2006-2009) project, which undertook an extensive study of twenty outer London suburban town centres. Within the Adaptable Suburbs project this particular research stream focuses on how the theory of multiple centrality within urban street network systems links to the development of London and its suburban centres through time, and the changing spatial relationships between the suburban and the urban. Many of the theoretical starting points of this thesis, and the rationale for case study selection, stem from both projects and are referred to accordingly where appropriate in the analysis.

To carry out this research the historical reconstruction of the street network of four case study areas around the centres of Surbiton, South Norwood, High Barnet and Loughton for the past 130 years is carried out, that is then analysed using space syntax techniques and theories. This is then complemented with highly detailed reconstructions of the built form in Surbiton and South Norwood where all individual buildings within the study areas are reconstructed to create an analysis that accounts for the combined network and built form transformations that have taken place over the time period of the study. The suburban centres are then compared to one another, in regards to their spatial structure and built form compositions. Therefore a multi-dimensional analysis taking into account time, scale, location and form is enabled. By focussing on peri-urban areas, the analysis develops an understanding of the processes of urbanisation from the late 19th Century up until the present day, as this is the region of London that experienced the most growth during this period. Furthermore it will seek to answer questions about how, over time, the urban fringe makes the transition from predominantly rural to urban, and the socio-spatial implications for the patterns of growth and changing architectural forms that are observed. This is vital in understanding city growth processes and dynamics.

The proposed research contributes to several areas of current urban debate; How does the structure of urban space change over time to adapt to the changing structure of society and ways in which people that use urban space? What is the role of suburbs in the contemporary assemblage of the city? How have so-called *suburban* peri-urban areas adapted to their changing relationship to the city over time, through their spatial structure and built environment? How and why has the structure of peri-urban London changed over time to create the structure of the city that we see today? This research also seeks to move these questions beyond the current understanding by integrating research techniques from different disciplines and developing new approaches to historical urban research. Through these approaches this research moves towards addressing the question of: how and why has the urban form on the periphery of London come into being? Furthermore the analysis of the suburban areas will enable a clearer understanding of the relational qualities and specificity of the suburban through time. When does a suburb become a suburb? Is a suburb always a suburb? What has happened to historic fringe areas of the city as they become enmeshed in the continuous urban fabric?

This thesis is comprised of nine chapters, this being Chapter 1 and forming the introduction to the thesis. In Chapter 2 a review of existing literature is presented and the key avenues for further exploration are identified. Chapter 3 details the selection process for the case studies that are used as the basis for the historical analysis in the research: Surbiton, South Norwood, Loughton and High Barnet, alongside summaries of their histories. Chapter 4 presents an evaluation of the network models and representations that can be used in space syntax analysis, and is used as the basis to select the model for the historical reconstruction of the case studies' street networks. The methodology for the street network and built form reconstruction is then described.

Finally the issue of, and method for avoiding edge effects when analysing cut-outs of street networks is presented.

In Chapter 5 an overview of the spatial and structural properties of the London-wide street network model that was constructed for this research is presented, exploring the multiple ways to characterise the structure of the network alongside space syntax methods. The four peri-urban case study town centres are then compared using space syntax analysis to four centrally located sub-centres. This comparison is used to highlight the configurational similarities and differences between the centre and the periphery in the context of contemporary London as a whole.

Chapter 6 focuses on the historical street network development of the four case study areas across three historical periods and the present day: 1880, 1910, 1960 and 2013, using space syntax analysis as the basis to describe their spatial development. The case study areas of Surbiton and South Norwood are then analysed in greater detail through an examination of the changing relationship and structure in the dimensions of their configurational properties over time.

Chapter 7 moves the focus of the historical analysis from the network configuration to the built from. In this chapter the development of the built form is charted and compared statistically between Surbiton and South Norwood. The key findings are then explored further. Finally accounts of the changing land uses on the main commercial streets of Surbiton and South Norwood over the period of analysis are presented. This structure to the analytical chapters enables a shifting downwards in the scales of the analyses that are presented, from the city scale (Chapter 5) to local urban area (Chapter 6) and finally building scale and associated land uses (Chapter 7).

Chapter 8 presents the discussion of the key findings from the analytical chapters through theoretical exploration and consideration of the relationships between the findings from the various strands of analysis that are presented across the preceding chapters. The conclusion is presented in Chapter 9, summarising the key findings, and potential future avenues for enquiry that this research has shown to be central to understanding the processes of spatial and architectural peri-urban development. Each chapter has a distinct coloured tab on the top right of each page to aid navigation. Four A3 overview maps of the case study areas can be found in the rear slip pocket. These are intended to be used in conjunction with Chapters 5 onwards as a visual cross-reference for locations discussed in the text. In addition to these overview maps, eight

A4 maps are also in the rear slip pocket. These are larger reproductions that illustrate more clearly the detail of the reconstructed building footprint records for Surbiton and South Norwood.

2 Review of Existing work

2.1 Introduction

In order to be able to approach the subject of urbanisation, and that of the urban periphery more specifically, this literature review presents a summary of the key thinking and theories about the process of urban development and function that this research is based upon. This is from both the physical and sociological viewpoint. The body of work that is covered is that which has influenced and guided the approach to this research, extending beyond physical urban morphology research into theories of urban function. The intent of this research is to develop and enhance knowledge of the process of urban development through empirical data analysis combined with an understanding of the relationship between the physical and social components of the city. The relationship between the material form of the city, and its role in the social functioning of the city is key to understanding the nature of both historical development, and possible future trajectories, as urban expansion continues across the globe.

2.2 The City and the Urban

2.2.1 Urban Systems Research

Urban systems and studies as a topic of research have existed for a significant period of time. Whilst this research has developed significantly there are still fundamental questions about the nature of cities that have yet to be addressed. Whilst the earliest studies of the city relied on basic inference, as scholarship has advanced the way that urban research is approached has developed into what is regards by many today as a science (Batty, 2014). The advances in urban research that have occurred in the 20th century are linked closely to the development of the computer and the quantitative revolution of the 60's that allowed complex geographical research to be carried out on a large scale for the first time (Barnes, 2001, 1994). It is from this research into the spatial structure of cities and urban assemblages that this research originates in its philosophical approach by using quantitative methods to understand the socio-spatial nature of the development of the periphery of cities, specifically London. Whilst the capacity to carry out quantitative research today is greater than it has ever been due to the constant advances in computational power, the issues that are now faced relate to the data and analytical methods that are used for quantitative analysis (Jacobs, 2009). This issue is central to this research and to the wider domain of data-led urban research. The issue that arises is that of data production and analysis. The computational power available to research is such that huge datasets can be processed and analysed in numerous way in order to interrogate their contents, but the questions of how and why this is being done are highly important. The data at the heart of this issue is commonly referred to as big data (Manyika et al., 2011), due to the advances in technology generally and the proliferation of connected digital interfaces between infrastructures within urban systems, and generally within society, data is being produced automatically on a huge scale, and there is a drive towards the integration and analysis of this data. Whilst having the data available, and the computational power to analyse it is generally a positive situation for researchers studying urban systems, how to analyse the data is a significant issue that is yet to be addressed. Furthermore concerns have been raised, that with the deluge of data, the nuanced approach of smaller scale and humanistic approaches is being ignored, to the detriment of understanding the particular (Portugali, 2013). In this research the proposed scope is extensive, and it will be necessary to address the issue of how to handle large datasets in such a way as to be able to usefully analyse data from spatial networks at the urban scale to individual built forms.

Cities are complex systems that are made up of a multitude of both physical and social components and systems that interact dynamically over time creating emergent phenomena and the development of new spatial and social forms (Batty, 2007, 2013; Portugali and Haken, 1996, 2000, 2001, 2003; Portugali, 2011; Portugali et al., 2012). In understanding the city as an assemblage of dynamically interacting components that create non-linear emergent properties, strategies to approaching analysis of physical urban systems and forms have to take into account the multiplicity of actors and actions that are embedded within every part of the city. Due to this overwhelming complexity of urban systems, it is useful to analyse certain components of the system that allow insight into the social functioning of the city. The city is an inherently spatialised system, whereby relationships are embedded into the spatial ordering of the city, this concept is not new (Burgess, 1923; Christaller; 1933; Losch, 1940; Hoyt, 1939; Harris and Ullman, 1945) but the early approaches to understanding the relationship between the social and the spatial have moved beyond simplistic areal and conceptual models to look at the spatial configuration of urban networks in order to understand their social meaning (Hiller and Hanson, 1984) and their morphological developmental trajectories (Alexander, 1965; Batty and Longley , 1994). The latest development into the research of urban systems has also brought in the physics discipline, applying methods from that domain to the analysis of urban networks and morphology (Barthelemy, 2011; Louf and Barthelemy, 2013, 2014), aiming to bring the knowledge from their domain and apply it to the 'big data' of urban systems.

It is within this realm of urban morphological research, which seeks to understand the relationship between the social and the spatial that this research situates itself. Acknowledging the complexity of urban systems, the research aims to understand the specific historical evolution of particular systems of the built environment and their linkages to the social environment, so that an account of the socio-spatial development of the periphery of London can be developed. The central work in linking the social and the spatial within the realm of architectural research is that of Hillier and Hanson (Hillier et al., 1976; Hillier and Hanson, 1984) that developed the idea that the ordering of space, or configuration, from the building scale, to the urban scale reflected fundamental aspects of social relations, and through understanding the spatial organisation of societies, an understanding of the underlying social processes at work could be developed. This was termed the syntax of space; now commonly know as *space syntax*. This work is closely linked to the developments in social network analysis that sought to understand the nature of social dynamic based on networks of relations (Freeman, 1977, 1979), but extended into physical space, by seeing physical networks of space created by society as reflections on the social ordering implicit within them. The ideas of space syntax also indirectly elaborated on certain aspects of complexity theory that developed at a later date, as applied to urban systems and even notions of psychogeography in regards to the relationship between time and space. The relationship between society and space is constantly shifting, but the material artefacts of the social ordering are not so readily adaptable due to their physical nature. Therefore, as society develops, it is influenced by the socially constructed ordering of space that is already in-place. The effect of past decisions on future outcomes is know in the complexity sciences as *path dependence*. The theories of space syntax are also acutely aware of the non-linear processes that occur in urban systems, whereby the physical infrastructure of the city that already exists affects behaviours and spatial relationships, whilst the city is constantly being remade, by those aiming to adapt the social ordering of space to the new social realities of the time (Hillier and Vaughan, 2007). It is the same historical resonance of the past ordering of space, within space syntax theory, that reflects post-modern psychogeographic understandings of the effect of historical processes on the present and how they percolate through time in specific places, through the physical, psychological and social traces left from previous eras. It is through this lens of understanding the process of urban development and the influence of the past on the present, and how the process of urbanisation reflects a changing society through spatial and architectural re-working, that this research aims to explore the process of urbanisation.

The evolution of street networks over time brings about a fundamental transformation of the urban system through changing the potentials for movement and co-presence in space (Griffiths, 2005; Griffiths, 2009) and the ability for the city to enlarge but maintain a functional ordering to the connectivity of the city, through the street network (Masucci et al., 2014). A central aspect of this is the impact of the existing network on future development. Whilst this is a research area that has not been exhaustively researched, concepts widely used within the discussion of cities and complexity science are that of *path-dependence* and *lock-in.* These concepts can be usefully applied (Batty, 2007; Batty 2013) in understanding that structures from the past influence the future trajectory of development (Arthur, 1988) and that certain decisions create conditions that cannot easily be reversed in the future. In the study of urban morphological development this can be understood to be physical structures of city growth, such as the road network and other transport infrastructures that are mediated by planning processes. This is particularly relevant to understanding the development of semi-rural areas made up of sparse grids, as they are transformed into more densely connected urban-like grids (Oliveira and Pinho, 2007). During this transformation the pre-existing structure will heavily influence the location and primary structure of connectivity that the area will be dependant on in the future, due to the dependence of the area on the pre-existing network for connectivity to the wider region (Serra and Pinho, 2012), as will the planning policies that influence the development of either sparse, dispersed grids or concentrated areas of dense grid development. In the case of London the structure of growth has been heavily influenced by the bounding effect of the greenbelt policies enacted in 1953, aimed at limiting urban sprawl (Masucci et al., 2013), itself the product of mobility technology development (Sheller and Urry, 2000). This policy decision has contributed to the structure of the city that is seen today, that will itself influence future urban development. This non-linear system of policy implementation and urban development creates a complex system of relations that influence each other recursively through incremental changes brought about by each development. Understanding how the past influences the present is vital in looking forward to future potentials for development, in both the spatial infrastructure and built form. On the urban-fringe this is especially the case. Through understanding the trajectories of past growth, and what the consequences of particular forms of urban growth have led to in the present will be able to inform future planning that can facilitate adaptable and sustainable urban forms for future development (Serra and Pinho, 2011).

Space syntax, as a set of theories and methods, which have been actively developed for 30 years, has extended its theoretical base beyond the symbolic relationship between society and urban space into the realm of the socio-spatial functionality and cognitive of the ordering of space (Hillier, 1997, 1999, 2007, 2009; Hiller et al., 1993, 2005). Central to this understanding of the way in which society and space interact and structure each other is the notion of centrality in networks of space. Centrality in network - as mentioned earlier in the context of social network analysis - is the degree to which a certain element or connection within a network is central to its structure. The degree of centrality of an element can be defined in several ways, but in space syntax research, when applied to urban networks of space it is defined in two ways. Firstly it is the number of times an element falls on the shortest paths between all other network elements, the shortest path being defined by the angular change required to traverse a certain path, this is commonly known as betweenness centrality within the network analysis literature, but is referred to within the space syntax research area as *choice*. The second way in which centrality is defined is the proximity of one network element to all other network elements, again in relation to the total angular change require to traverse the network and reach all other elements. In the network analysis literature this is referred to as closeness centrality and in the space syntax research areas as *integration*. These measures have been shown to correlate with pedestrian movement flows (Hillier et al., 1993): to a location *within* a network, in respect to integration, and *through* a location in respect to choice. The space syntax methodology of urban network analysis has been further extended through the development of the Place Syntax tool (Stahle et al., 2005, 2006). This tool combines the configurational analysis of space syntax with extra variables, such as trip attractors, place function characteristics and population density. By combining these variables into the space syntax analysis, the pedestrian movement predictive power of the modelling process was shown to improve over configurational analysis alone, in the case of a heavily planned non-organically developed urban area. Overcoming the problems of configurational analysis of areas with limited organisational spatial logic. Centrality as a concept through which to understand and analyse the city has become wider spread and accepted as a useful approach, for both analysis and planning, through the extension and addition of measures of centrality to those that are commonly used in space syntax research (Porta et al., 2010; Porta et al., 2013). A set of methods referred to as Multiple Centrality Assessment (MCA) (Porta et al., 2006; Crucitti et al., 2006) has been developed that is used to investigate multiple dimensions to the structures of centrality in urban networks. This has been shown to correlate with the locations of commerce and activity (Porta et al., 2008), further highlighting the importance of centrality to the functioning of urban systems. It has also been applied to investigating the relationships between the centralities in different urban transport infrastructures, highlighting the need for synergies in the centralities and connectivity between different forms of transport networks to enhance efficiency and usability (Porta and Scheurer, 2006). Through further developing our understanding of the evolution of the structures of centrality in urban systems, nuanced and considered approaches to planning can be developed that work with the pre-existing and inherent spatial ordering that is found in cities.

From the foundation of work on the spatial ordering and the social implications of the city, a theory of the movement economy of cities was developed (Hillier, 2007) that sought to understand why cities are structured in such a way as to order flows to specific locations, and how these flows created economic and social dynamism in cities, as well as creating patterns of land-use. The concept of the movement economy allows for historical research to understand the changing dynamics of the potentials for flows through an urban system. Hillier and colleagues propose that fluctuations within the structuring of flows will also allow insight into the competing social demands of certain periods and how this is reflected in the spatial structure and mobility potentials of the city that is afforded by spatial networks. These affordances are postulated to be brought about the multiple, and pervasive centrality that occurs across all scales in urban systems (Hillier, 2009). Central to the flows of movement in the city and the theorised movement economy is the concept of co-presence. When multiple people, who may or may not know each other, occupy a shared space co-presence is brought about (Urry, 2002; 2007; Hillier 1997). The sharing of space with others affords the opportunity for exchange from the most basic level, such as visual awareness through to the highest level of verbal and physical exchange. Movement is central to this, as it allows for new potentials for exchange to occur in new locations between constantly changing individuals. How the structure of the urban space brings this about is referred to as natural movement. This is the proportion of movement through and to certain location in the urban street network that is brought about purely through the configuration of the network (Hillier et al., 1993). Through the natural movement and co-presence generated by the configuration of the street network exchanges from the most basic to most complex, create new understandings and realisations of the world around us, facilitating changes to occur through the combination and re-combination of new forms and ideas. This constant flow of information in the city enables them to continually drive forward creativity (Florida, 2005). It is this sharing of space and potentials for exchange that is suggested to be the building blocks of society based on mutual exchange and understanding (Hillier, 1996; 2007). This is closely intertwined with technological and mobility developments, as over time space is radically restructured as the potential for co-presence to occur in both spatial and a-spatial forms changes accordingly. Through studying the evolution of the structure of the city and the spatial relations that its structure affords at specific periods through the structuring of mobilities brought about by the natural movement of the urban configuration the changing possibilities for co-presence and exchange can be understood. Furthermore through understanding how these potentials for movement and co-presence have changed the structure of the potential for exchange in a specific period can be understood allowing insight into the possible spatial interaction that there was and how this has changed up to the present day – and the way in which the experience of co-presence and potential for exchange is different today in comparison to the past.

2.2.2 Representation in Space Syntax and GIS

In space syntax research the basis for the investigation of the interaction between people and urban form is the street network. The most common method of analysis uses a modified representation of the street network based on network elements called axial lines that represent the longest line of sight within a convex space that connects to adjacent spaces (Hillier and Hanson, 1984; Turner et al., 2005). This representation of space creates a network model of space that captures the connectivity and size of the space with the fewest possible network elements. The axial line representation of space has been shown to produce a specific model of the city that is closer to the cognitive representation that people use to navigate the city (Hillier and Penn, 2003). The study by Lynch (1960), *The Image of The City* is considered one of the foundational evaluations of how information about the structure of urban environments is encoded in the mind. The primary components of the mental representation of the city that Lynch identified were: paths, edges, nodes, districts and landmarks. Portugali (2011) expands on these ideas to create a detailed account of how the informational components of the city interact to create a functional and understandable system, even through cities in their totality are beyond the comprehension of the human mind.

The synergies between space syntax and spatial cognition were investigated by Peponis et al (1990), exploring the relationship between configurational properties and observed pedestrian behaviour. This paper found that signage and architectural differentiation alone were not sufficient to explain wayfinding behaviours, and that configuration had to be taken into account. Following this study, different aspects of wayfinding have been successfully examined using space syntax analysis including multi-level buildings (Holscher and Brosamle, 2007) agent simulation (Turner and Penn, 2001) and the use of virtual environments (Conroy-Dalton, 2001). Recent methodological development expands on the theory, finding that using angular distance (Iida and Hillier, 2005) to measure accessibility provides a more accurate representation than metric or topological distance in relation to observed pedestrian behaviour. This is due to the similarities in how geometry is simplified in cognitive representations of space, and angular change forming the basis of space syntax analysis of spatial networks. Through basing space syntax analysis on the angular properties of networks it more closely approximates the geometric simplification that spatial relationships are subject to in the mind (Dara-Abrams, 2006), and therefore the analysis reveals a structure of the city that is closer to mental representations based on the simplest geometric structures, than other network analysis methodologies. Thus creating the necessary link between the cognitive, lived experience of the environment and analytical framework (Kwan, 2000)

Ratti (2004a, b) has criticised the axial line method of representing road networks, claiming that it can lead to situations where small adjustments to the built-form layout produces radically different axial representations. Whilst this criticism has been addressed in subsequent articles (Hillier and Penn, 2004), Turner (2007) shows that this concern can be addressed substantively through the utilisation of road centre line network representations. In this network representation multiple network segments that follow the centre-line of the street area being modelled can represent a space, as opposed to the single line segment in the axial model. This leads to a situation where there may be multiple network segments between network intersections (This is discussed at length in Chapter 4). In order to overcome the differences in the representation of space in the road centre-line model a different approach, developed by Turner (2007) can be used in the calculation of choice, called segment length weighted choice. The value of choice of a segment is weighted by the length of the segment that is the starting point and end point for the shortest angular path it falls along. The logic to this approach to weighting is that the longer the starting and end point segments the greater the likelihood of trips originating or terminating within them due to their greater spatial extent. This greater spatial extent increases the likelihood of a greater volume of trips passing through a segment that falls on the shortest angular path between them, giving them a higher choice value. It should however be noted that there is no such thing as the perfect – or singular – data source. All maps, and thus all map-derived network models, are subject to inconsistencies and discrepancies due to the methods employed to represent the real world.

Geographic information systems (GIS) and geographic information science (GISci) are respectively the computerised systems for the storage, analysis and visualisation of spatial data and the theory and methods associated with them. GIS and GISci has its origins in computerised cartographic production, with the first systems capable of analysing spatial relationships emerging in the late 1960s and since then developing into an entire software industry and profession associated with its application (Coppock and Rhind, 1991). Within GIS research the methods and forms of representing spatial data is a fundamental concern, as it forms the basis for all the analysis that is derived from the data, and the forms of analysis that are possible (Goodchild et al., 2007; Miller and Wentz, 2003; Miller, 2000). Within GIS systems the basic forms of spatial data are either vector representations, that capture discrete spatial entities, comprised of point, line and polygon geometries, or raster based surfaces that are used to represent surfaces with continuously varying values across their extent (Longley et al., 2010). Within space syntax research the axial line and road centre-line representations fall within the vector data model classification. Choosing the correct form of representation is a vital aspect of the research process that has to be carefully considered from both the data type, vector vs. raster, that real-world geographic structures are represented with, and also the level of detail, or the resolution of the representation (Miller, 2000; Mark, 1999). This level of detail can be referred to as the level of generalisation, or abstraction that the real world geographic entity is subject to, through the process of representation within GIS data structures (Longley et al., 2010, Goodchild et al., 2007). For example, the axial line is a highly abstracted representation that does not relate to a physical geographic entity in the real world, but the perceived spatial unit of the longest line of sight within a space bounded by built forms. This is generalised according to the detail at which the longest line of sight is considered. Features such as trees and other barriers will affect possible lines of sight. Taking these other variables into account will increase the complexity of the representation, and also the detail that the model captures, creating a less abstracted model of the real world. Depending on the research that is being carried out different levels of detail and forms of representation are necessary to answer particular questions that might be asked of the data (Kwan et al., 2003).

In the context of historical geographic scholarship utilising geographic information systems as the platform of analysis, data availability and representation become especially important. This issue is widely acknowledged within the historical GIS (HGIS) field as being one of the primary barriers to greater levels of geospatial research using historic map data (Southall, 2013; Gregory and Healey, 2007). This is due to the necessity of deriving and extracting historic geospatial data from map resources to make them interoperable with contemporary vector based data representations, which requires extensive time resources (Gregory and Ell, 2007). Enabling and defining the processes and resources that should be used in order to accomplish this task is one of the key challenges to the HGIS research field, and historical spatial analysis more generally (Knowles, 2008; Gregory, 2003; Gregory and Southall, 1998). Developing the processes and approaches to this task can benefit all research areas concerned with historic spatial analysis. In historical urban morphological analysis the issue of historical map data capture that has been explored in relation to constructing chronologies of urban street networks (Pinho and Oliveira, 2009; Serra and Pinho, 2011). The method that has been developed for this specific task is referred to a cartographic re-drawing. This historical GIS data capture process works through the deletion of features from a contemporary data when overlaid on the preceding period. This satisfies the necessity of having data of historical periods being interoperable with contemporary data in order to carry out comparative analysis (Gregory, 2003), and also minimises the time-cost by minimising the need to digitise geographic features from scratch. This is a highly specific method that only deals with one type of geographic feature and representation. The methods and approaches to the capture of features such as buildings and other areal entities from historical maps for analytical purposes are not yet developed and methodologies to do so are necessary to advance HGIS scholarship.

2.2.3 Social component and dynamics of centrality and the movement economy within the urban system

Hillier's (2009, 2009) work on multiple and pervasive centrality and the structural and the social function of centrality in the city suggests that the city is a product of the minds of those who inhabit it; from the perspective of how we understand and navigate space and also how we build space to conform to our need for co-presence, and the city's reliance on the movement economy. The development of movement potentials and co-presence is also seen in the types of technological innovation that take place whereby telecommunications technology is seen to destroy space and overcome its confines (Graham and Marvin, 1996). This idea of technology can equally be applied to technology that enables city and inter-city time-space compression, such as road surfacing technology, automobiles, trams, trains and air travel. It is important to note that this 'time-space' compression is less of an actual and more of a perceived change due to shifting relationally brought about through technological innovation.

Technology can be thought about as the hyper-accelerated process of human evolution whereby we extend ourselves through our intellectual abilities, extending our (dis)embodied presence beyond our physical capabilities (Mitchell, 2004). The spatio-temporal extension of ourselves is said to fundamentally bring about radical forms of co-presence in man-made technological space. Telecommunications technological space is more easily conceptualised abstractly than the similarly man-made technological architectural space of the city. This is also a socio-technical creation although far more complex and difficult to grasp, one that can be similarly conceptualised as a socio-technical construction supporting mobilities and flows

(Graham, 2001). This begs the question as to why we as humans expend such resources and time as to bring about co-presence, and this in turn leads to the question of ‘what is the role of co-presence within the movement economy of the city, and is there such a thing as a spatial-economy of co-presence?’

The idea that the city relies upon movement structured by the built form as to bring about co-presence in space is logical, from both the biological standpoint for the exchange of genetic information between individuals, but also the more abstract information that circulates and is exchanged constantly between individuals in the city and the built form of the city (Hillier and Hanson, 1984, Hillier, 1996, Harken and Portugali, 2003, Lynch, 1960, Portugali, 2011), through co-presence brought about by the structure of urban space, that is itself created through human action. This leads to the question; ‘why do we create cities, or in broader terms socio-technical assemblages, as to bring about co-presence and heightened affordances for mobilities and flows?’

This question can begin to be approached through the ideas of collective creativity developed by Csikszentmihayli (1996) whereby creativity and social change does not come about through the actions of one genius or a single originator of an idea but the process of innovation and creation is in fact the product of the social that the individual inhabits and is part of both corporeally and mentally. It is suggested that this is the fundamental process that drives human development forward. This idea of creativity arising from the social assemblage of individuals has been applied widely in various guises (Florida, 2005, Landry, 2000) although never explicitly in regards to the relational spatial structure of urban form. This social space that creativity stems from can then be turned to and we can begin to ask the question; ‘What is the role of urban space in the process of creation?’ and ‘what role does structure of urban space play in the enabling of innovation in society?’ This has been utilised in thinking about the structure of internal building spaces (Sailer, 2011) and specifically the emergence of the arrangement of built forms in urban space (Hanna, 2005), through the idea that we as individuals do not actively try to innovate but do so through the constant ‘making sense of the city’ that leads to new perspectives due to the unique interpretation that each individual creates in the perceptual space of the mind, and then feeds back to the perceptual space of the others that we are co-present with in physical and technological (relational) space. This has not been applied conceptually to understanding the relational structure of the city network but in understanding the power and value of the configuration, or accessibility of space, the notion of *spatial* *capital* has been developed (Marcus, 2007), that aims to capture the economic configurational value of the urban fabric, by combining space syntax network analysis techniques with other spatial variables. This quantifies the inherent value of the structuring of space in terms of the potential for exchanges, both social and economic that is generated by the configuration of space and the location of services and destinations. Understanding the value of configuration and location within urban systems is an important step in creating a system to value urban form that has up until now not be possible. .

The idea of complexity of the urban assemblage described by Jacobs (1961) and perused quantitatively in relation to complexity science in understanding the structure and function of cities as ordered chaos and fractal structures (Batty, 2005, Batty and Longley, 1994, Portugali, 2006) can be utilised in conjunction with ideas about innovation and creativity. One premise of complexity theory is that we are not in a steady state system but actually in a system that is perpetually changing through instabilities; the purpose of complex systems is to bring about change through the emergent properties of small-scale action and interaction (Batty, 2005, Prigogine, 1997). It is this very instability that is central to the ability of the system to function and adapt. This instability can be seen in the social-sphere but there are stable structural properties of centrality in the relational street network of the city that persist through time and alongside social and technological evolutions. There is then a tension for the need for social instability that is not too unstable as to be deleterious, with a need for a structure of space that can be understood and is stable. Through this the structure of urban space can be seen to be a form of collectively designed stability in relational topological form of multiple and pervasive centralities in the structure of city space as to bring about relational instability amongst those elements that inhabit the spatial structures of the city. This instability in the system can be defined as the perpetual possibility of change brought about by the action and reaction of individuals who inhabit space and interpret and re-interpret the world around them, creating new understandings and therefore actions within space, with co-presence being the locus of the possibility of creativity and production through exchange. This is framed within the structures of the built environment that influence the possibilities of co-presence and the relational possibilities between people in urban space.

Multiple and pervasive centrality in the spatial development of urban form over time the city can be thought of as a structuring of a complex system as to create the conditions for social relational instability and change through the stable relational spatial topology that it exhibits. This appears to be contradictory, as a stable relational spatial framework for interaction would suggest non-variance but it is this very structure that creates stability of change, or more precisely a socially sustainable continuity of change. It is suggested that the instability stems from the semi-lattice (Alexander, 1965) of centralities allowing city wide and local networks to occupy the same space and therefore create non-linear circulations of movement and action.

As the population increase in an urban area over time, the urban structures and infrastructures will have to become more complex, containing multiple layers of networks working at different scales, in order to maintain the useful relational typology between the inhabitants across scales, therefore the proliferation of multiple scaled centralities is necessary to engage a greater density and number of people in a coherent urban system that is both efficient and understandable. The structures of centrality are also vital in allowing the movement and engagement with and between different scales of centrality. This ability to be both in a local and global space at once and to move between centralities quickly and with little effort are key in the development of heightened mobilities and co-presence and also the ability for 'being' in multiple scales and spaces at once. Through this we are connected corporeally to an extremely high degree, creating the affordances for co-presence across scales extremely efficiently both spatially and temporally and thus the potentials for 'informational co-presence' (Griffiths, 2008) are greatly increased through and across all scales of centrality. This allows for the potentials for human action arising from these non-linear interactions to be heightened.

It is of particular importance to understand how the development of local centres has taken place, due to the importance of local centres in everyday life (Vaughan et al., 2010; 2009). It is through the continual small-scale daily routines, that our experience of the world is shaped and our understanding formed (Urry, 2002, 2007). Whilst the city's overall form and structure is the subject of much debate and analysis, local centres are the places where the everyday is experienced and the locations where social relations can be developed through repeated co-presence brought about by daily routines and movements (Southerton, 2006). Furthermore, in London, small local centres play a vital role in the economic life of the city (Vaughan et al., 2009). To generate an understanding of how the city creation process occurs and the potential impacts this has on those who inhabit it necessitates an analysis that takes into account both the city scale, and the local scale of the small town centre where the activities of the everyday are played out. An important aspect of the understanding the spaces of everyday life and how cities have evolved is the transformation and emergence of new social spaces through changing land uses. Of particular relevance is the concept of third place, or third space originally developed by Oldenburg (1989). In these spaces, which are neither the home (first place) nor work (second place), socialisation can occur between individuals away from the social and cultural norms of the first two types of place, allowing new social and cultural production (Oldenburg, 1997). Through understanding the changing land uses over time, and how this relates to the movement potentials generated by the configuration of the street network, readings of the importance and function of specific land uses within everyday life can be elucidated (Griffiths et al., 2013).

The outlined theoretical framework of understanding the role and function of centrality can be conceptually mapped onto the fringe, or suburban areas of the city. The theories of the background and foreground network of the city structure (Hillier, 2002), is particularly relevant In this context Hillier (2001, 1996, 2007) proposes that there is a generic form to the city that is made up of foreground and background networks. The foreground network is that which spans the whole space of the city, linking together the sub centres of the city at all scales, maximising the co-presence brought about by the natural movement generated by the configuration of the grid (Hillier et al., 1993). Situated on this foreground network the principal economic activities of the city are proposed to be located. The background network is theorised to be the portion of the network relating to residential space and activities (Hillier, 2001, 2002, 2007). This portion of the network is suggested to be configured according to the social and cultural priorities of the society in question, in order to structure co-presence and spatial relations between particular sections of the population. Although this theory has been explored in terms of urban network configuration, a greater understanding of the evolution of urban form and the associated land uses that arise in relation to the theorised foreground and background networks is necessary to further develop the conception of the generic form of the city, and the fundamental relationships that exists between configuration and activity within the city. An examination of the periphery of the city synonymous with the background network and characterised as residential, will allow a clearer understanding of the nature of the internal spatial function of these areas. The configuration of local centres and the routes that link them together amongst the background residential spaces will reveal how the potential for movement and co-presence is structured. Understanding this in relation to the centre will allow insights into the differences between the centre and periphery that account for the potential forms of sociability that they engender

Given that the peri-urban is the relative background to the city scale network Linking to the theories of the foreground and background structure to the configuration of the city network is the theory of the deformed wheel super-structure of city street networks (Hillier et al., 1987, Hillier, 1989; Hillier and Vaughan, 2007). The theory of the deformed wheel structure is that in cities which have developed from the bottom up in an organic fashion, develop a city-scale high centrality structure of radial routes emanating from the centre, linking to a circular ring structure of high global centrality on the edge of the city, or in some cases multiple ring structures progressively further from the centre. Although this has been observed at the city level as well as the local level (Hillier, 2002; Hiller and Vaughan, 2007) the spatial mechanisms through which these structures develop over time has not been explored. An account of the historical development of deformed wheel structures in urban networks will allow for a greater understanding of the processes and stages through which they take shape, informing the understanding of their role and function in urban systems. Furthermore, through understanding the development of local deformed wheel structures in relation to urban scale deformed wheel structures, the theories of nested overlapping structures within cities, developed by Alexander (1966), can be more fully conceptualised.

These nested, overlapping structures of high centrality that are found in the network structures of cities are synonymous with local centres (Hillier, 1999). When centrality analysis on urban street networks is carried out at varying radii different types of centres are revealed (Vaughan et al., 2007). It is the relationship between these centres functioning at different spatial scales that bring together the overall spatial structure and function of the city, as a nested network of centres (Hillier and Penn, 1996). Examining the relative centrality characteristics of central and peripheral local sub-centres has the potential to reveal the spatial mechanisms through which they operate and relate to one another in the overall city system. Furthermore through examining the historical development of local centres and their relationship to other proximate local centres a greater understanding of the fine-grained city creation process of the knitting together of local centres, creating a network of centres, can be brought about.

Particularly relevant to this is the notion of *active centres* (Vaughan et al., 2010) and *live centres* (Hillier, 1999). Live centres are the locations where the grid is structured such that movement is generated in certain locations, where due to the through and to-movement of people, activities and land uses, such as retail occur. Active centres refer to the both the live centre and the surrounding area, where activities that do not necessarily rely on movement but benefit from it and have certain synergies with locating near to live centres occur. Over time as the street network develops these live and active centres will change and expand, shifting the relationships to surrounding centres creating new structures of centrality and movement potentials in the urban grid. The dynamics of this development are key to understanding the city creation process. Relating the through and to-movement potential of locations in the network by analysing the spatial coincidence of the locations of the peak values of betweenness and closeness centrality (Hillier et al., 1987) allows for a clearer understanding of how local live and active centres function and create networks of centres, that bring about co-presence of people in particular places and the land use activities associated with this (Vaughan et al., 2009; Dhanani and Vaughan, 2013). Charting the historical process of the development of overlapping paths of the highest centrality and co-present forms of centrality is necessary to understand the historical movement potentials and trajectories of growth in the urban grid as it develops from loosely linked centres to a highly interrelated network of centres relating in different ways at different spatial scales.

2.3 The Suburban, Peri-Urban and Urban Fringe

2.3.1 The Edges of the City

Whilst this research focuses on the edge of the urban area of London as it is today, the research does not aim to label the areas as a particular parts of a formal typology of urban fabric and does not aim to situate them pre-emptively, within the context of standard categories such as suburban, edge-city or peri-urban. Doing so would undermine the position of urban configurational research as discussed earlier, that proposes that no place is a fixed contained entity that can be delineated and labelled, but is related and functions across scales in differing ways and through differing mechanisms of movement and exchange. However, understanding the current conceptualisations of the edges of cities, the region that this research focuses on, it is necessary in order to effectively situate the research findings against a range of readings of the meaning and function of the edges of the city.

Whilst the term suburbs is itself highly problematic for the purposes of this section, due to its widely understood, and in fact contested nature, the word is employed in the discussion of the varying views and positions taken on the nature, form and function of the edges of the city, due to its currency as the primary descriptor of the urban areas in question, and its international recognition as a specific urban typology (Stanilov, 2004), however problematic this may be (Vaughan et al., 2009). The term urban fringe is used to describe the interface between the urban area and the surrounding rural or semi-rural land (Pryor, 1968; Wehrwein, 1942). This interface between land use areas has been labelled interchangeably as, peri-urban (Adell, 1999) and edge city (Garreau, 1991, 2011). The urban fringe has been an area of interest to urban researchers due to its frontier-like nature, forging out, and urbanising new territories (Garreau, 1991, 2011), creating new composite landscapes of competing uses. In the context of London the predominant conflict between urban expansion and edge of the city is that of the protected area of the greenbelt, encircling the city. The politically designated greenbelt semi-rural transition zone highlights the competing tensions between idealised imaginaries of landscape and urban expansion, and the continuing tensions between an urbanising world and rural origins (Kiel and Shields, 2013). Understanding the urban forms that occupy these contested fringes allows for a more critical appraisal of the urban-rural relationships in these areas. Urban areas have continued to grow, and with the continual urbanisation of the global population the fringes of the city are locations where the new growth occurs and is sometimes characterised as sprawl, particularly in North American contexts (Brueckner, 2000). Importantly, urban forms similar to the urban fringe can also be embedded within, or in close proximity to the centre, such as in the case of informal settlements in developing countries such as the favelas of Rio, Brazil (Vaz and Jacques, 2004). In these cases they can be understood to be the fringe of the city in a social, political and economic sense rather than purely a spatial one. It is through the lens of the assemblage of multiple land uses and spatial forms intertwined with the social, economic and political relations with the urban area as a whole that this research situates itself within. By gaining an understanding of the changing nature of the urban periphery as a composite of multiple factors and actors, the historical evolution of London's peri-urban forms can be better understood and an analysis that understands an urban system as a set of relations that change over time and scale can be developed.

2.3.2 Suburbia

The meaning of suburban as a concept can be traced back to the earliest spatial arrangement of settlements. The term suburban is derived from the Latin *sub urbe* meaning beneath or below the focus of the settlement, *urbs*, which could have been a castle or a fort in early examples, but predominantly the spatial arrangement was such that the *sub urbe* was situated beyond the walls that defined the centre of the settlement (Harris and Larkham, 1999). This terminology to describe the relationship between the periphery and the core continues today in the use of the term suburban, still connoting an inferior position of the periphery relative to the centre (Vaughan et al., 2010). The contemporary differentiation between the urban and suburban is more complex, relating to multiple social and economic factors (Harris, 2010) beyond simple spatial arrangements. Central to this is the perceived relationship and differences between the urban and suburban. Even though the populations of peripheral areas often commute to the centre of the city for employment purposes (Van Der Laan, 1998) and in some cases commuting in the opposite direction (Glaeser, 2001), thus intertwining the social and economic life of the city across the spectrum of urban space they are spoken of a separate or different. The spatial notion of the urban can thus be seen to be a continuum of a diverse set of social and economic relationship occurring across space. Creating definitions of urban or suburban is not necessarily useful and a better approach is to create local understandings of places and their relationships across all spatial scales, from their hinterland to the wider urban region (Vaughan et al., 2009).

The British suburb is a particularly heavily studied urban form that has elicited multiple opposing viewpoints. Suburban developments have been argued to have a diverse public life, allowing them to adapt to change and become part of the urban fabric over time as the urban area expands and further develops. It is through the relationship between the suburb and the city, and the internal relationships in the local area that the role of the suburb can be understood from the viewpoint of its inhabitants (Vaughan et al, 2010). A particularly crucial aspect to the discussion of the perceived nature of suburbs is their historical development. A great body of literature has been written that has explored the sociology and history of the development of suburbs, primarily focussed on the expansion of the railways (Jackson, 1978; Weightman and Humphries, 1984; Wolmar, 2013) and the social improvement that they aimed to bring about by depopulating the undesirable, at the time, centre of the city. These accounts, whilst providing much needed insight into the dynamics between the railways and urban development, do not fully account for the significance of the settlements or local spatial historical topology and its influence on the development of areas into what are considered suburban settlements. Whilst historical studies of particular epochs in city/suburban development abound (e.g. Hebbert, 1998) an historical perspective of a city's change over time is a quite different aspect that this research aims to address by empirically studying the spatial and architectural development of peri-urban London over 130 years. The commonly repeated notion of the suburbs arising purely out of new forms of mobility in the city is problematic in itself, as it views them as new phenomena when they have a history dating back thousands of years (Vaughan et al., 2009; Simon, 2008). Understanding them instead not as something new, but as an inherent part of the urban form, whatever particular local form they may take, is important in reconceptualising the role and function of the periphery within the overall urban assemblage.

Suburbs are often seen as a dependant of the main centre, but the fact that suburban morphologies can vary enormously over a small area is often forgotten (Vaughan and Griffiths, 2013). This leads to the role of local, smaller suburban centres to be overlooked in the policy and urban research domains, which have instead preferred to focus on the city centre (GLA, 2008). Many conceptualisations of suburbia have been explored across research domains, but they mostly frame the suburb in a particular ideological image that situates it as an inferior or ancillary (sub) to the urban proper, the centre. The contested nature of the term ‘suburb’ indicates it is poorly understood and worthy of examination in order to understand the varying conception of suburbia (Vaughan et al., 2009; 2010).

The common conception that local centres primarily function as retail locations has been disputed by academics for some time (Vaughan et al., 2009, Vaughan et al., 2013) and recently reassessed by policy professionals re-examining the role of local centres (BIS, 2011) due to the declining commercial viability in the context of changes consumption patterns brought about by Internet shopping. This wider recognition of the importance of the role of local centres within areas considered to be suburban (GLA, 2011), for the social life of the area, indicates that they are becoming to be considered more than just dormitory towns that are a source of labour for the heart of the city. This deeper and widened understanding of local town centres necessitates a re-evaluation of the planning policies and framework through which they are judged in order to encourage a fuller range of activities to take place to ensure their success in the long term is not reliant purely on retail, but a range of activities reflecting their role in local communities.

In the context of London’s suburban development, mobility infrastructures have played a vital role in the expansion of the urban area. In London the expansion of the railway systems to the urban fringe has been said to dissolve the boundaries of the urban area imposed by historic travel time and cost constraints (Hebbert, 1998). The spatial and architectural impacts of mobility technologies and their impacts on the suburban landscape will be explored further in this research. Aside from the social and spatial aspects of the development and functioning of English Suburbia, the architectural forms that have developed and been adapted to the social demands of the time have been examined at depth. Throughout the work of Whitehand at Birmingham University (1975, 2001; Whitehand and Larkham, 1991; Whitehand et al., 1999, 1999) the development of specific built forms of residential suburban areas have been shown to reflect social processes and changes. The built form of suburbia is proposed by the Whitehand school of urban morphology to have the capacity to adapt over time through accretive extension and additions, as well as developing new forms such as garages in response to the rise of the personal motor vehicle. These nuanced and detailed accounts of the changing built form capture at the finest architectural scale the evolution of suburban built form, but do not create generic understanding of urban growth through their limited spatial scope, which focuses directly on issues of historic architectural and spatial data and research methods.

2.4 Research Questions

From this review of existing work and themes within current debate on urban form, suburbia and peri-urban areas generally, this research seeks to answer the following questions. This aim of these questions is to enable a clearer understanding of what the peri-urban is and how has it arrived at its present state. In order to achieve this a historical approach to the analysis of configuration of the street network and built from is employed. The historical approach to the research necessitates the evaluation and development of specific methodologies relating to geospatial data creation since the data required for this form of analysis has not been constructed before. The primary and secondary questions that this research addresses are as follows:

‘What are the morphological centrality and built form characteristics of peri-urban London as it has developed over the period 1880-2013?’

‘How can GIS and Space Syntax research methodologies be combined and enhanced to enable efficient and detailed, large-scale historical analyses?’

The first question is framed within the concept of centrality as developed over the last 50 years across diverse investigations of networks and network theory; social network centrality analysis (Freeman, 1979, Freeman, 1977), social network analysis of historical geographic phenomena (Pitts, 1978) spatial and social network dynamics (Borgatti, 2005, 2006, 2009) and specifically centrality and networks in relation to studies and conceptualisations of the form and function of urban space; overlapping scaling centralities of urban structure (Alexander, 1965), social centrality in urban systems (Craven and Wellman, 1973), economic aspects of centrality in cities (Bird, 1977), the social construction of network centrality and theories known as space syntax (Hillier and Hanson, 1984, Hiller 1996, Hiller, 1999, Hiller, 2009) and universal properties of the structures of centrality in urban systems (Crucitti et al. 2005). This study will focus upon the idea that urban form develops as to create multiple centres across all scales (Hillier, 1999, 2009, 2009) that are social-technical structural artefacts, created and mediated by social forces that underlie the city creation process (Hillier and Hanson, 1984; Hillier, 1996; 2007). These social forces are in turn influenced by the built form of the city, in the structuring of locations of movement and activity, creating a process of iterative socio-spatial development (Hillier, 1997) The main research question can be split into two basic components:

What have been the patterns in the development of peri-urban London's street network in the period 1880-2013 and are there coherent structural patterns to this development?

How have the built forms that populate the street network developed over this period, and are there specific forms associated with peri-urban areas?

2.5 Summary

The research of urban systems and the edges of cities is extensive and takes in many viewpoints and research approaches. Computational tools, methods and approaches, to analysing cities have developed over the last 50 years, allowing new insights into how they function spatially. Alongside these tools of analysis, theories about the form and function of urban systems have been developed that attempt to explain the social function of the spatial structure of cities. The theories of space syntax aim to unite the social and the spatial by gaining an understanding of how they influence one another. Such a linkage between the social and spatial makes it possible to analyse certain aspects of the form of cities to understand the social structures that are played out within them. Central to the theories of space syntax is the notion of the movement economy, which proposes that the diverse social and economic life of cities are shaped by the co-presence afforded by street configurations. This co-presence also plays a vital role in the development of the society that experiences it. The movement of people that occurs in cities and how it changes over time enable new socialities to emerge.

The edges of cities have been subject to various studies that examine their unique spatial character and relationships with the wider urban area. They are often the confluence of multiple scales of movement and activity. These areas are often typecast as *suburban,* yet this term masks the diversity of the places that it is supposed to represent. Peri-urban areas have a rich spatial history that is an intertwined story of both their local history and city-scale changes that have constantly reshaped spatial, architectural and theoretical understandings of the relationship between the centre and periphery over time. This chapter suggests that a historical analysis of the edges of the city that takes into account the local and city-scale spatial relationship alongside its architectural development will provide a richer understanding of how edge city built form can function generatively or conservatively. The next chapter presents the methodology for the case study area selection and an overview of their historical development, prior to the contemporary and historical analysis of the changing urban fabric in subsequent chapters.

3 Case Study Selection and Background Information

3.1 Introduction

In order to carry out the proposed research, the identification and selection of suitable case studies is necessary to focus the research spatially, in order to enable the questions and research objectives set out in the previous section to be adequately addressed. Due to the highly detailed nature of the proposed network and built form analysis, the amount of time required to construct the data sets makes the use of the whole of London as the case study prohibitive, therefore individual case study areas need to be selected. This chapter presents the reasons for the choice of the selected case study areas, and also a brief account of their local histories to provide an introductory understanding to them as places, and how they have developed over time, both locally and in relation to London as a city region that they are embedded within through various infrastructures.

3.2 Case Study Selection

The aim of this research is understand the spatial and architectural process of urbanisation in the context of peripheral urban areas. The time scale that the research is being carried out over is approximately 130 years. With these considerations in mind the selection of the case studies requires the identification of areas within the London city-region that have experienced significant urbanisation over this period. This will allow for the subsequent analysis to examine the characteristics of change in the street network and built form development that occurs during urbanisation, and potentially suburbanisation, if it is found that this has distinct characteristics.

The area that is considered to be London for the purposes of this research is the area bounded by the M25 orbital motorway, this is the most significant physical spatial network feature that bounds and delineates the area of London. Detailed historic maps were studied for the c. 1880 period to find areas that were not part of the continuous urban fabric at that time, with low or non-existent urbanisation and in subsequent mapping from the later time periods of 1910 and 1960 became enmeshed or highly connected to the urban area with the development of transport infrastructures. To be able to further focus the selection of locales, cases were selected using the rationale of the research carried out during the course of the Towards Successful Suburban Town Centres research project at UCL (SSTC, 2006-2009), which had been used to identify town centres that fulfilled the requirement of being smaller town centres that form the background of activity away from the primary outer London large town centres such as Croydon, Ealing and Kingston. The SSTC project had found that it is in the smaller town centres where collectively there is a greater level of commercial and other town centre related activities than in the larger centres, concluding that these smaller centres are a vital background of activity to the larger outer London centres and London more generally (Griffiths et al., 2008). The final criteria for choosing the four cases was that they should be distributed across the London city-region so that they would be representative of the urban growth that occurred in all directions away from the centre of London in order to identify any differences this may bring about in their developmental trajectories. From the research that was carried out in the SSTC project and the criteria of having experienced significant urbanisation over the period of this study, and should be spatially diverse in their locations in respect to the centre of London the four cases that were selected were High Barnet, Loughton, South Norwood and Surbiton, as shown in figure 1.

Figure 1 Contemporary London road network showing case study locations with the M25 London orbital road highlighted in black.

3.3 Case Studies Town Centres' Overview and Analysis Area

The four cases were considered both broadly, to capture their wider spatial setting, but also more narrowly, in order to focus on the building, land uses and detailed spatial network characteristics of an area around the town centre. In order to do so, a study area had to be defined for both these purposes.

The assignment of boundaries or specific point relating to and area is a highly complex and problematic issue in geographical research, especially when reconciling the space syntax and quantitative approaches to GIS research. Whilst in GIS research it is quite normal to define a study area in terms of standard data capture areas (such as census areas), in space syntax the study area is defined according to the area of interest (building, public square, neighbourhood), from which a radius of 2.5 km is drawn in order to encompass the wider spatial setting of the studied area and to eliminate any concerns with edge effect. Edge effects occur when subsets of networks are analysed that are cut from larger networks and the analysis is affected by the absence of the adjacent network area. This is discussed in detail in the next chapter. An additional consideration is that this study (and the research project with which it is associated) needed to reconcile two divergent scales of analysis: one which took account of building scale changes in use and built form and another that took account of regional shifts in street network.

In this research that combines both GIS approaches and space syntax analysis these two approached had to be reconciled, therefore boundaries had to be chosen that would then be expanded upon so that a larger area that accounted for differing scales of relationships could be implemented. This was achieved by making the study area of analysis a six-kilometre radius around the town centre of the four selected named places. The boundaries of the town centres of the four case studies that are used in this research are shown in figure 2. These boundaries were produced by the Greater London Authority (2004), in conjunction with University College London and the Centre for Advanced Spatial Analysis. The boundaries were the result of a spatial statistical modelling exercise that took into account factors such as, land use, intensity of use, diversity of use, commercial turnover and visitor attractions. Whilst this is not a definitive study, as town centres cannot be definitively described or artificially spatially bounded, it is the most comprehensive study of town centres in London ever conducted and due to the backing and recognition of the Greater London Authority, in an urban planning context the boundaries that were produced are widely recognised and understood, making this research more able to converse across disciplines.

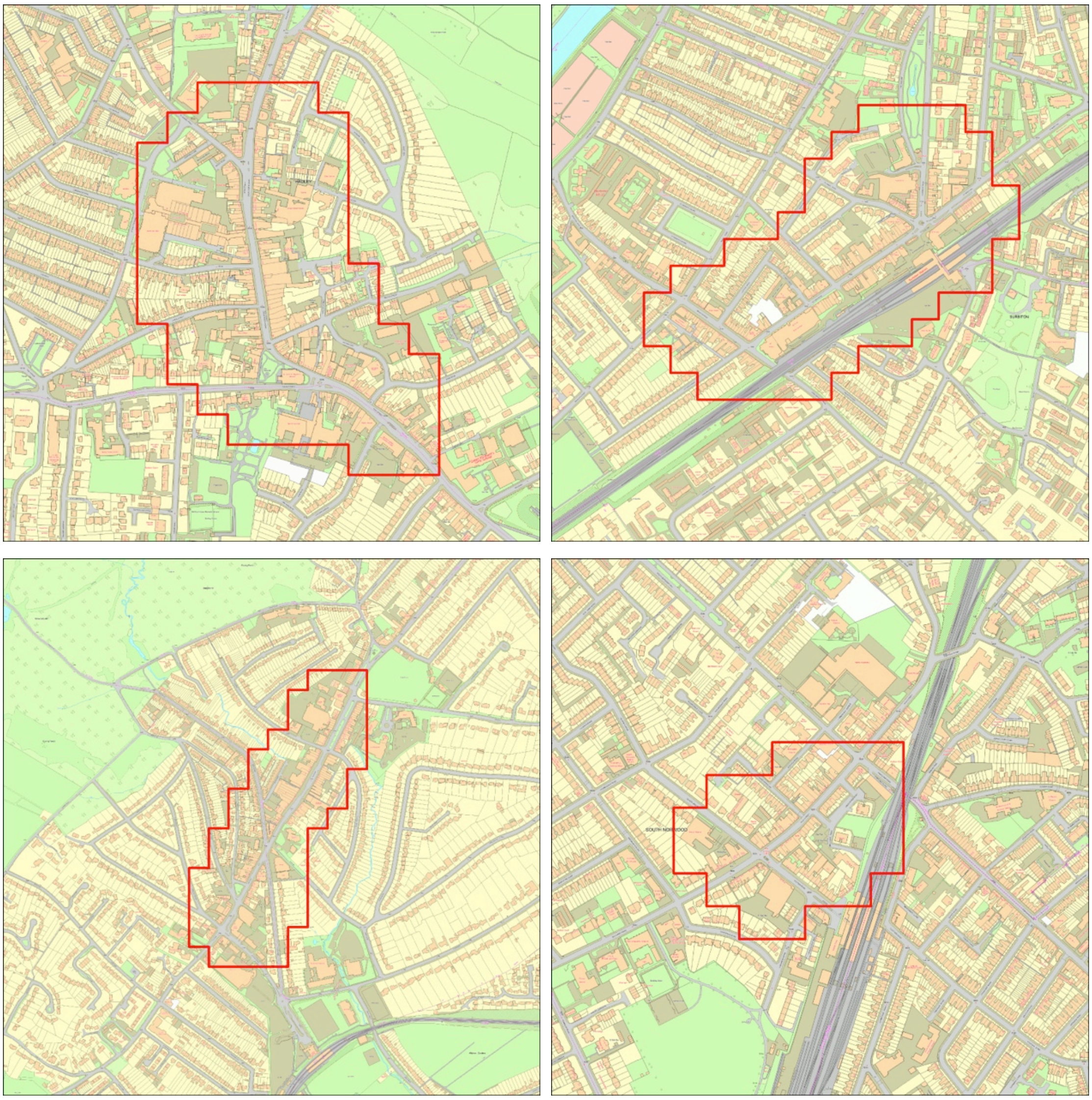


Figure 2 Town centre boundaries of case studies. Initially produced by Greater London Authority in collaboration with University College London and the Centre for Advanced Spatial Analysis. Clockwise from top left: High Barnet, Surbiton, South Norwood and Loughton.

The statistical town centre boundaries that are shown in figure 2 - and for the purposes of this research represent the central core of the case study areas - are used as the starting point to define a larger region of study. In figure 3 the study area for each of the case studies is shown. The study area for the street network reconstruction and subsequent space syntax analysis is a 6km radius around the town centre boundary (figure 3). This gives a study area for each of the case studies of approximately 118 square kilometres for which the street network was reconstructed for the three historical periods of analysis. By using this enlarged study area the locales that are being examined can be considered in terms of very local spatial properties and also regional properties, in terms of how they connect to other local centres and the morphological properties of the wider region. However the actual analytical outcomes of the space syntax analysis only focus upon the central 3km radius of the study area.

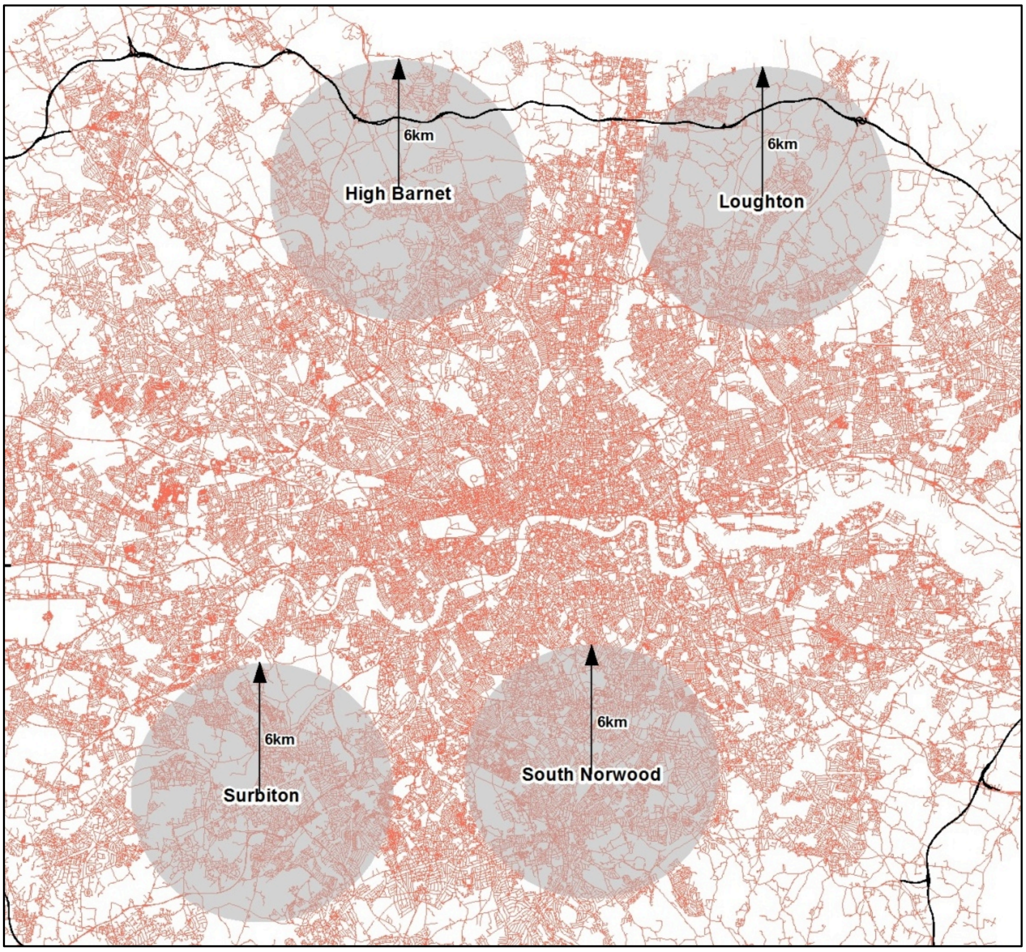


Figure 3 Areas around case study town centres which the street network is reconstructed for (118km2 each/total 360km2 area of reconstruction). London street network shown in red, M25 orbital motorway shown in black.

3.4 Case Studies: Background and Historical Information

This section provides a historical background and general overview of the four case studies to provide a context to understanding them as places within the London region.

3.4.1 Surbiton

Surbiton is located in the southwest of London, as can be seen in figure 3, within the Royal Borough of Kingston-Upon-Thames. As shown in figure 2, the main high street runs along a northeast-southwest axis, similarly the railway line also runs along this axis. In figure 4 the historical time series of the central area of Surbiton is shown. These three time periods are the ones that are used for the historical reconstruction of the building footprint record and the street network, the present day data being available.

Surbiton itself is the product of the development of the railways. When the London to Portsmouth railways line was proposed, the town of Kingston-upon-Thames, located north of present day Surbiton, rejected the plan to locate a station there due to the belief that it would damage the coaching trade that was important to the area. Instead, the railway station was located close to the centre of present day Surbiton. The station opened in 1838 and was initially called Kingston-Upon-Railway. Surbiton as a named area came into existence in 1855 when it was named as a local government district. The development of the area following the construction of the railway station was driven by a businessman called Thomas Pooley, who saw the potential for the area to be developed as a location for commuters into the city of London to live. He purchased the land around the station in 1839 and began a project of residential development in the area after the local farmer who owned the land died. This was the first development in the built form of the area. Since then it has grown and continued to be a major residential area with good transport links to the centre of London that people use to commute to their places of work. The significance of the railway and the conflicting interplay with new forms of transport technology, namely the railways and coach services in the development of the area is significant, as will be shown later the emergence of new forms of transport infrastructure play a key role in the spatial development of the area.

Figure 4 Historic mapping of Surbiton town centre

3.4.2 South Norwood

As can be seen in figure 2, South Norwood is located in the south-southeast of London, almost due east of Surbiton, in the London Borough of Bromley. The town centre is also located adjacent to the northwest of the railway station as shown in figure 5. The time series of maps shows that South Norwood has developed around the train line and station. This railway line and station also play an important role in the history of South Norwood. The station opened in 1839 under the name of Jolly-Sailor Station due to the proximity of a pub by the same name. This station formed part of the London to Brighton railway line. Previous to the opening of the railway station and the urban development of the area it was covered by oak forest. This oak forest covered much of the area around South Norwood, its name deriving from its location within the wooded area, called the Great North Wood. The Croydon Canal also featured prominently in the development of the area with housing and businesses developing along the section of the canal that ran through South Norwood. Brick manufacturing was a significant local trade throughout most of the 18th and 19th Century with brick drying fields visible in historical maps; the location of one of these fields is now a park named Brickfields Meadows. Following the construction the railway the area gradually developed into a residential area with direct links to London for commuters. The area is also close to the site of The Crystal Palace, which was the location of the Great Exhibition in 1851, destroyed in a fire in 1936. This building is present in the two earliest historical building footprint reconstructions shown in later chapters.

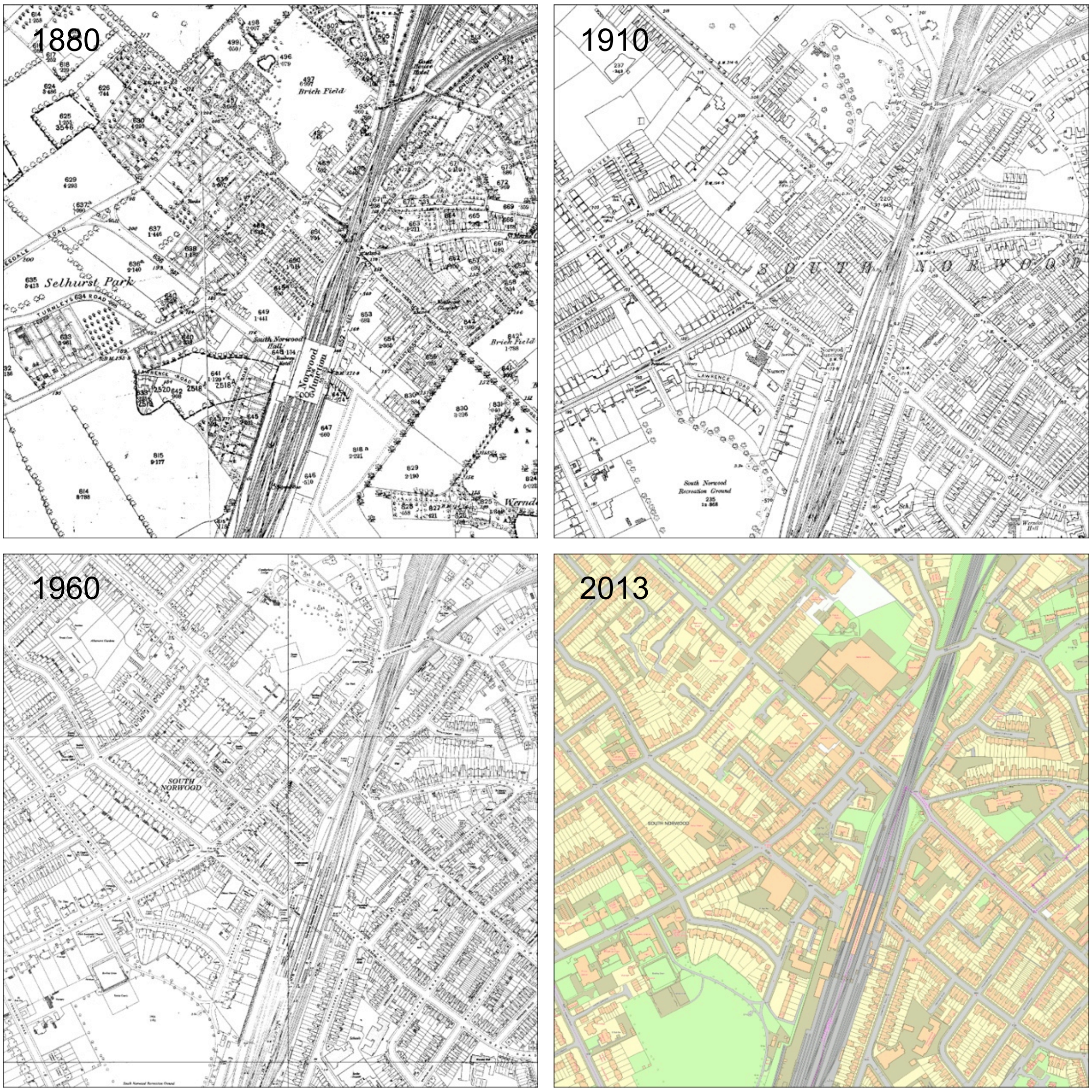


Figure 5 Historic mapping of South Norwood town centre

3.4.3 Loughton

The town of Loughton is located in the north west of London (figure 1 and 2) and is situated just outside the administrative boundary of London, within the County of Essex. Once again the town is situated close to a railway line, providing links to the centre of London. The historical time series maps of the town centre in figure 6 show that in the earliest period that this study examines there was very little development of the area and was mainly open farmland and forest. Loughton as a named place has records dating back to 1062 when the first recorded named settlement in the location of present day Loughton can be found. A settlement in the same location as present day Loughton is also mentioned in the Doomsday Book of 1086 as *Lochintuna*. To the northwest of Loughton is Epping Forest that was given Royal Forest status in the 12th century to be used as a royal hunting ground. The forest today falls under the governance of the City of London and is a protected area that cannot be built upon. Throughout the forest's history it has been used for the manufacturing of charcoal through the pollarding of trees, evidence of which can still be seen today. The first significant development of the town came in the 17th Century when the road through Epping Forest was built; this turned the town into a stopping point for coaches travelling from London to Cambridge and East Anglia.

The subsequent development of the town occurred when the railway line was constructed close to the town and the station opened in 1856. From this period onwards the town slowly grew until the 1930s when the suburban development of London was at its fastest pace, as can be seen in the transition between the 1910 and 1960 maps in figure 6. The railway line was electrified in 1948 and became part of the London Underground Central Line rail network. Following this integration with the London Underground the town has continued to grow slowly, but remains constrained by the presence of the protected area of Epping Forest at its north-western edge.

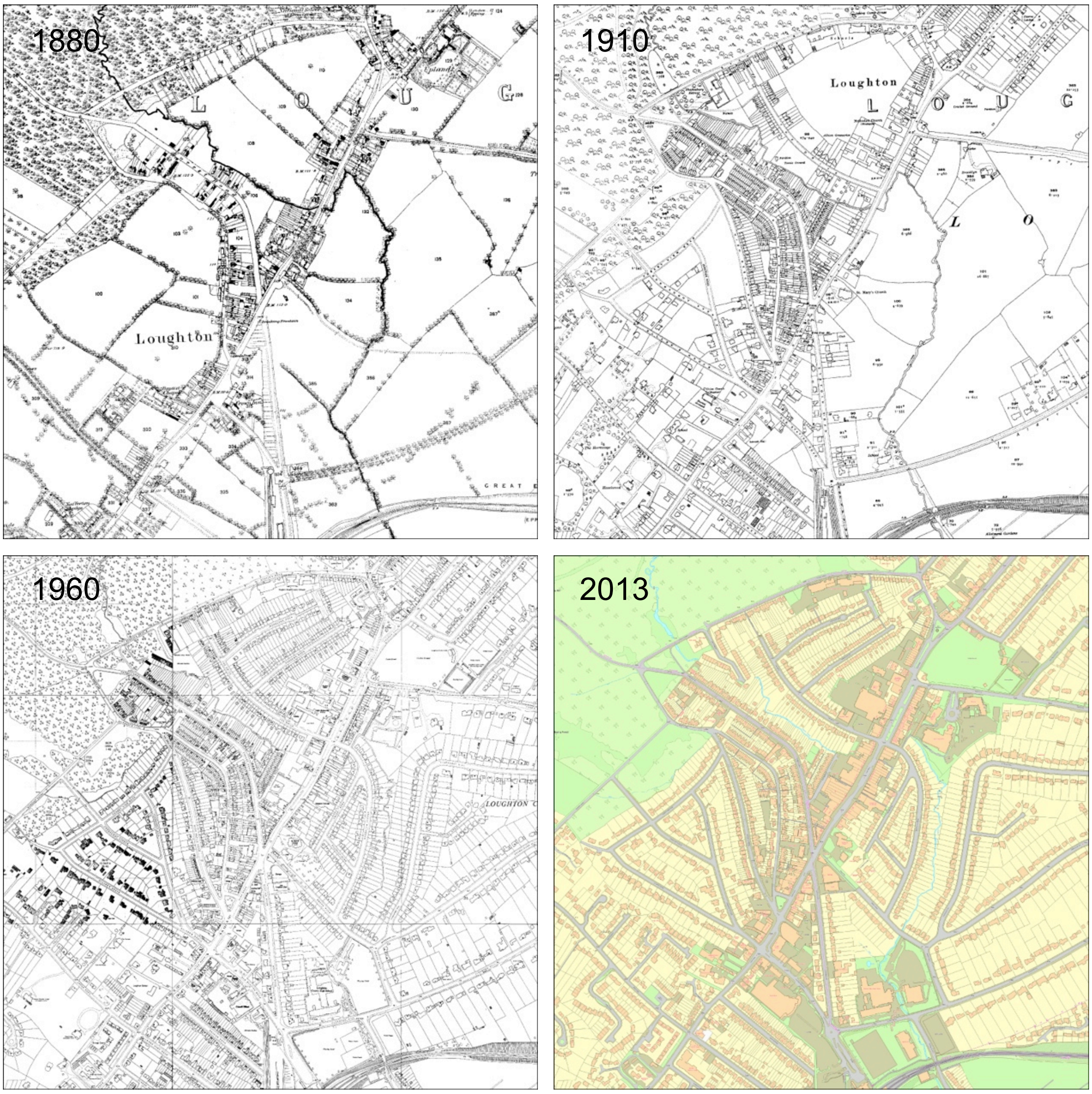


Figure 6 Historic mapping of Loughton town centre

3.4.4 High Barnet

High Barnet, more commonly known in the past as Chipping Barnet, is located in the north-northwest of London (figures 1 and 3) within the London Borough of Barnet. It has been a London borough since 1965; previously it was part of the county of Hertfordshire. Settlement in this area can be traced back as early as the 12th Century when records of a settlement of Barnet can be found. The town centre is located on the historic Great North Road linking London to York and Edinburgh. The most significant architectural landmark in the area is The St. John The Baptist church to the south of the town centre that was erected in 1560 and remains to this day. To the southeast of the town centre is the London Underground Northern Line terminus station of High Barnet. There has been a station in the vicinity of the town centre since 1872 when it was the end point of the line between Finsbury Park and Edgware. The line and station were then incorporated into the London Underground network and the London Underground station in the same location was opened in 1940. Today it is primarily a residential area on the edge of the administrative boundaries of London, bordering Hertfordshire.

Figure 7 Historic mapping of High Barnet town centre

3.5 Summary

The selection of the case study areas that will be used for the historical reconstruction and analysis is vital to ensure that the analysis is capable of evaluating significant change over time. In order to ensure this, the case studies were selected using a variety of criteria, specifically spatial variation in relation to central London and significant change over time in their urban morphology. Further to these requirements the focus upon smaller centres was decided upon, since they collectively comprise the majority of outer London economic activity yet do not receive a representative amount of attention due to their fragmented spatial and administrative nature, yet they are vital to the overall functioning of London as a city due to the collectively high levels of economic and social activities that occur there. Finally the areas of interest identified in the UCL SSTC project that were identified as town centres within the Greater London Authority's town centre analysis were used to narrow down the case study option to four areas that would be the subject of the historical analysis. The selected areas of High Barnet, Loughton, Surbiton and South Norwood fulfilled these specific requirements and are the case studies that are used in this research.

In order to delineate a centre of the study areas that is compatible with GIS practices, boundaries or central points were required for each of the selected case studies. The boundaries for each of the town centres that were chosen, were those developed by the Greater London Authority. These boundaries are the most comprehensive statistical boundaries that take into account multiple variables that relate to the notion of town centred-ness. The boundaries are also officially recognised, therefore potential findings of the research will be more conversant with current planning thinking. These boundaries were then expanded upon spatially to cover a larger area so that the morphological analysis can take into account both the town centres themselves, and their morphological situation and evolution in relation to the surrounding area.

For each of the case studies a brief overview of the history was given. Across all four cases it can be seen that they have a range of diverse histories. Surbiton developed almost exclusively due to the arrival of the railway station; South Norwood's emergence also resulted from the arrival of the railway and the canal system. High Barnet and Loughton on the other hand, existed long before the railway systems or canals, with both acting as staging posts for those journeying to and from London. These diverse histories further enhance the variability in the selected case studies. The role of the railways must be highlighted as the arrival of this new transport infrastructure allowed for the spatial expansion of London and the growth of all four case study areas. It also facilitated the creation of residential areas outside the city centre due to the reduced travel time to the city centre, where most employment is situated, enabling the emergence of commuting over longer distances.

4 Data Appraisal and Methodology

4.1 Introduction

This chapter brings into focus the particular research area and specific research questions that this research addresses. The literature review in the previous section dealt with the topic of urban development and morphology as a whole, with a particular focus on suburbia, and aspects of morphological and GIS research. The research that is presented here is primarily concerned with understanding the spatial development of the fringe areas of the city through time as they have transformed from semi-rural to part of the continuous urban fabric and what are the implications of the stages of development that have occurred. Secondly this research address the methods that can be used to achieve it by integrating morphological and GIS methods to enable greater understanding from both disciplines of the overlapping nature of the research methods that are used in historical and contemporary urban spatial research. The integration of historical GIS and morphological research methods is approached from a data representation, generation and analysis viewpoint.

This chapter presents the methodological approaches and analytic outcomes undertaken to determine the most suitable method for creating the street network representations used for this research, and to also investigate in more general terms how different datasets from different spatial research domains can be applied to spatial architecture research. A comparative analysis of Open Street Map (OSM) volunteered geographic information (VGI) road network data, the UK national mapping agency Ordnance Survey Integrated Transport Network (ITN) road data and a hand-drawn Axial map for the area of Greater London is described. The three mapping options were assessed using space syntax segment analysis of the Surbiton area. Following the street network data evaluation the methods that are employed in the reconstruction of historic street networks and building footprint records in this research are described, and finally the method used to avoid edge effects when analysing sub-sections of street networks is presented. The historical reconstruction and edge effects avoidance methods that are presented aim to combine the best practices from the geographic information science discipline in the context of historical urban morphology research.

In the street network data evaluation angular segment analysis of the street network models is carried out using the ITN model, OSM model and hand-drawn axial model separately. The comparison of the network models is carried out through standard GIS processing techniques and the evaluation of space syntax measures computed within Depthmap software (Turner, 2007). The space syntax measures used are: segment length-weighted angular segment integration (a measure of network closeness) and choice (a measure of network betweenness) analysis at radii 800m, 2000m and *n* (or 'global'). These are explained in more detail in the following chapter. Comparative statistics are presented for the areas to evaluate the differing measures of each network model.

The OSM, ITN and axial London-wide networks have a total length of 29,700km, 26,000km and 20,000km respectively. The dramatic difference in network length alone demonstrates the divergent realities of the three mapping techniques and the representation of the world that they capture.

It was anticipated at the outset that the analysis would find that there was no significant difference in the global syntax values between the ITN and OSM and Axial models but at the local level the additional network segments for pedestrian routes within the OSM data would provide greater network accuracy and syntax values that model the reality on the ground better than the Ordnance Survey ITN model. Furthermore it was predicted that the OSM map captures potential pedestrian routes that are not present in the other data sets.

The evaluation presented in this chapter also sought to understand whether Volunteered Geographic Information (VGI) is a viable alternative to official mapping sources when creating models for analysis of small urban areas as well as the impact of model choice on space syntax analysis outcomes. If VGI data were to be found to be a reliable representation of urban space it would provide not only a cost effective alternative to commercially produced data but indeed a more reliable network model for the analysis to be carried out, due to the fine grain detail that it captures. Open source geographic data might have the potential to improve and enrich space syntax analysis whilst removing high price barriers that commercial data sources impose.

It should be noted that there is no such thing as the perfect – or singular – data source. All maps, and thus all map-derived network models, are subject to inconsistencies. Furthermore as computing capabilities and understanding of cities as integrated complex systems grow, the desire to carry out city scale or regional space syntax analysis is also growing. The construction of an axial map for very large areas is extremely time consuming and can lead to situations where the amount of time spent constructing the data can detract from attention that can be given to the analysis. Indeed, it is increasingly apparent that other sources of data may be relevant – such as road centre-line network data. Additionally, for larger areas, the effort required to capture axial lines may be significant.

Three mapping sources are compared for the creation of a segment map, which is a map that represents the street network as a set of lines broken at intersections. These are: the traditional method of tracing axial lines over raster maps at 1:10,000 and conversion to segment maps; segment maps created from road centre-line data; and segment maps created from open source maps drawn by volunteer users. The results of the evaluation relate directly to the choices that are made in the representation of the street network and urban structures (Miller, 2000). Therefore the question of how to model and represent city structures is of equal importance to the question of how to analyse them as they both have an impact on the outcomes independent of one another (Miller and Wentz, 2003).

4.2 Review of Road Network Data

For the purpose of this discussion three main types of road network data are discussed and evaluated. These are Volunteered Geographic Information (VGI) road centre-line data, national mapping agency road centre-line data and the hand drawn axial map.

Road centre line data presents the street network as a series of lines that follow the centre-line of the road (Fig 1) in contrast with the axial line, which is the longest straight line that can be constructed in any given urban space with unbroken visibility and accessibility. The hand-drawn axial map has been demonstrated as replicable using road centre lines that are weighted according to segment length thus opening up the possibility of using road centre-line data for space syntax segment analysis (Turner, 2007; Turner, 2009).

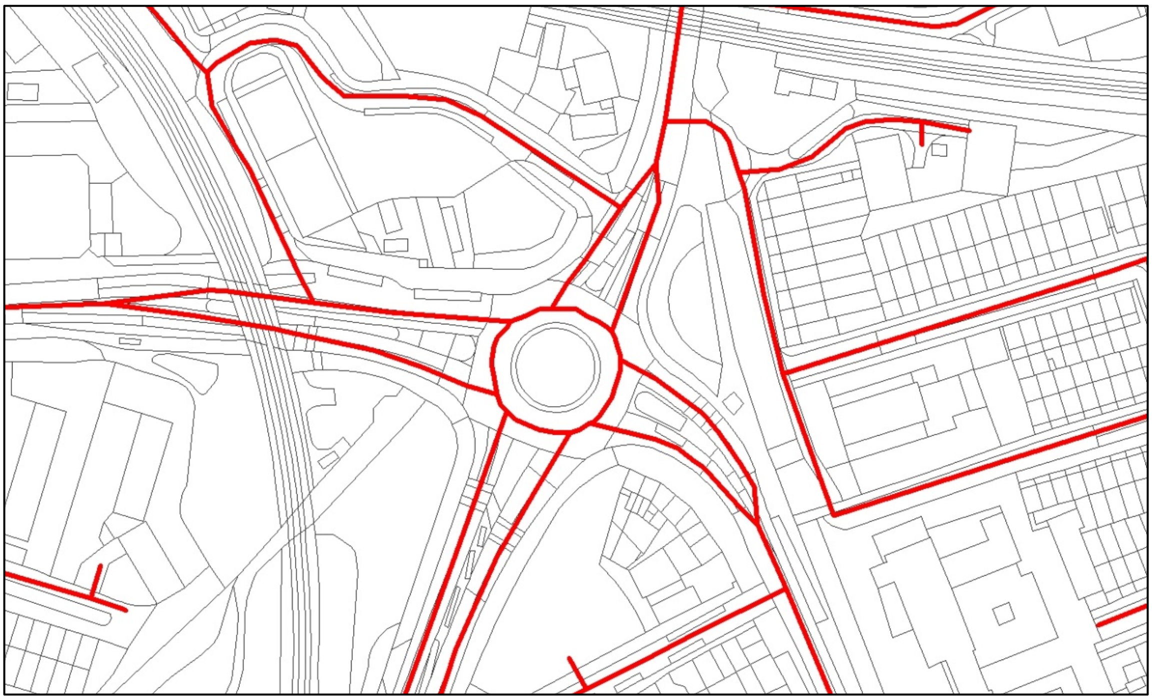


Figure 1 Road centre-line representation of a street network

The most common representation of street network data is in road-centre line format. This serves the purpose of government mapping agencies, whose primary purpose of creating the maps is for route solving problems. Such purposes may relate to in-car navigation, transport planning and emergency response planning. The necessity of a representation of the network that is close as possible to the physical reality is borne out of this. Notably this is a system that focuses on motorised traffic, rather than pedestrian flows.

Volunteered Geographic Information (VGI) Open Street Map

Volunteered Geographic Information (VGI) describes geographic datasets that have been compiled by members of the public who devote a portion of their time to the creation of geo-located information that is free to view and available to download from the Internet via web portals (Haklay and Weber, 2008).

A good example of this is the Open Street Map (OSM) (Fig 2) project started in 1994 by Steve Coast at University College London. Open Street Map is now the foremost VGI service in the world and provides coverage across all continents (OSM, 2011). The street network component of the OSM VGI data is created and supplied in road centre-line format. The data can be downloaded through web portals where the public, can obtain country and continent specific datasets at no cost (see: http://download.geofabrik.de/osm/ and http://downloads.cloudmade.com/).

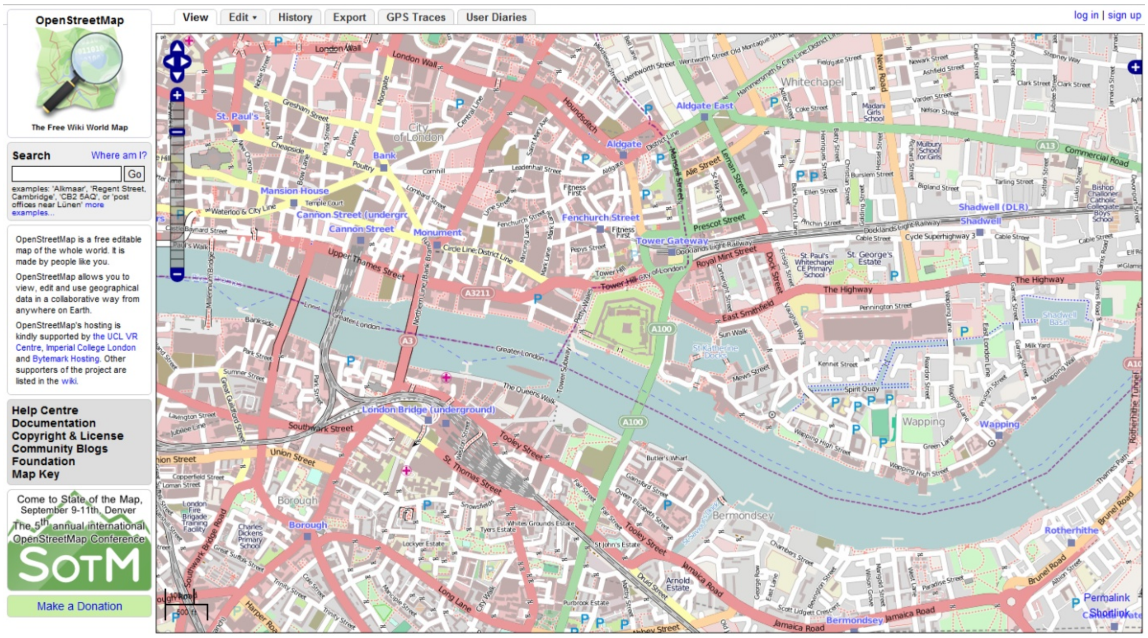


Figure 2 The Open Street Map viewer web page.

The process of the creation and compilation of VGI data is done is several ways, including on-foot data collection, aerial imagery digitisation and local knowledge. On-foot recording is where members of the public walk around an area with a hand-held GPS unit and record all the routes that they walk. The route data from the GPS(s) unit are then uploaded onto the OSM website. Here the data are checked and cleaned by the user and then published on the OSM website. The checking and cleaning process involves verifying the collected data is correct and any errors are removed. The user then adds attribute data such as the road name, road type and number of lanes.

The other principal method is through the digitisation of high-resolution aerial imagery. This is carried out by loading aerial imagery within the OSM data editor webpage and then digitizing roads, buildings and all other features that can been seen in the aerial imagery. Once this has been completed the same checking and data attribution as with on-foot methods is carried out before uploading to the OSM global dataset.

The final method does not involve the collection or digitisation of data but relies on local knowledge. People who want to contribute information for their local area can do so simply by entering the OSM data editor web portal and checking and changing the data that is already there for their local area according to what they know to be correct or incorrect about the area that they are knowledgeable about.

The question of primary importance in relation to VGI data is how complete and accurate is this dataset? Studies have been carried out in relation to this (Flanagin and Metzger, 2008; Haklay, 2010). From the studies it can be said that the quality of the data and the completeness is variable. It varies by country and then within each country, with urban areas generally being the most accurately mapped. In order to have a high level of confidence in the data, there need to be fifteen contributors who have edited the same area on average; with this level of participation the accuracy and completeness reaches 95%. There is also variable resolution in the features that are captured. Traffic management features such as road islands, will be captured in some areas whilst they may be absent in others. This reflects the differing views of those who create the data as to what should and should not be captured to create a complete representation of the environment.

Coverage of a given area is strongly linked to socio-economic profile, with more affluent regions having greater completeness and accuracy; this relates to the accessibility of the technology to record geographic data (GPS) and education relating to Internet technologies and mapping.

National Mapping Agency Road Network Data: Ordnance Survey (ITN)

The analysis uses the Ordnance Survey (OS) dataset called the Integrated Transport Network (ITN). Similarly to the VGI data it is supplied in the road centre-line format.
Unlike the VGI road network data this dataset is produced to clearly defined standards using traditional methods of surveying and verification within Geographic Information Systems (GIS). This means that the dataset has undergone rigorous testing to ensure that there is complete coverage, consistent connectivity across all network elements and that any errors are removed prior to publishing. Unlike the VGI data this is not free and costs at the present time £400-500 (600-750 USD) per square kilometre. This price puts it out of reach of many commercial entities (in the academic realm data are often supplied free of charge) that are not prepared to make the initial investment without clear beneficial financial reasons for doing so.

One key difference between the VGI data and the ITN data is that in the ITN dataset all road features are recorded. This includes all traffic management features which disjoint and fragment the network unnecessarily from the space syntax perspective but provide highly detailed information to those involved in transport planning and analysis, further underscoring the fact that this is a road-centric automotive dataset type (Fig 3) and not seen as a space that people inhabit and use or one that should be analysed from the perspective of the pedestrian.

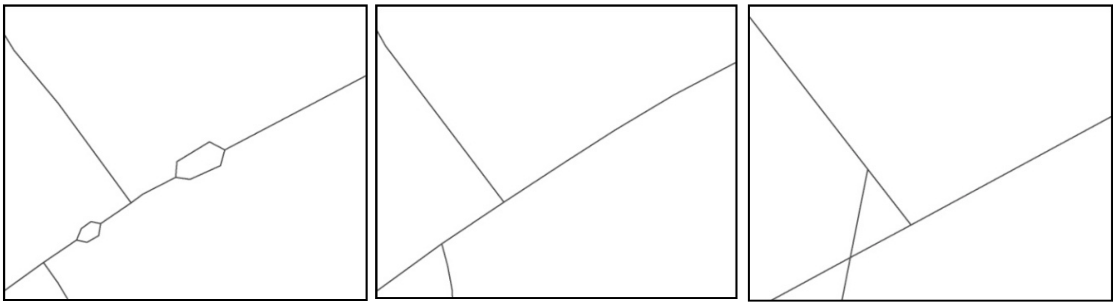


Figure 3 Traffic management features within ITN network (left) not present in OSM (centre) axial representation (right)

Axial Model Road Network Data: Classic Space Syntax Model

The final model evaluated is the axial-line map. The axial model of the street network is a representation of the accessibility and visibility that the built environment allows through its structure. The axial representation is constructed through the drawing of lines that show the longest lines of accessibility and visibility within a given built environment.

This representation of the street network is the one that space syntax analysis and research has been built upon over the last 30 years and is the fundamental premise of space syntax theory. It has been shown to function as the spatial unit through which the interaction of society and space can be analysed. This has been borne out in numerous established findings and has created a distinct research field. The use of the axial model differentiates the space syntax discipline from other urban network analyses in the way in which it represents space and therefore seeks to understand space.

The process that is used in the creation of the axial map is generally hand drawing. This process is completed by over-laying raster image maps and then the user draws the lines representing the longest lines of accessibility and visibility (indeed in early years, due to the lack of processing power, this was done using tracing paper overlaid on a paper map, with the axial line model then scanned and redrawn in the computer). This process can be advantageous in comparison to the pre-packaged data that the

VGI and ITN provide. The axial map incorporates local knowledge of an area in a 'ground-truthed' model that captures the required information contemporaneous to any social surveys that are carried out. The person who creates the maps can also develop a detailed understanding of the area through the process of creating the axial map.

Although the axial representation is well established and verified as a valid representation it does have several drawbacks. There is inherent inconsistency in the process of the creation of the hand-drawn axial map as it is not done in a uniform manner; differing scales of mapping may be used and the level of detail that the user observes may change as they zoom in or out (although this problem can be minimised somewhat by setting the computer to zoom only at fixed scales). These issues are also present in the VGI data but the principal concern is the time that it takes to create the model before any analysis can be carried out. For small urban areas axial maps are relatively quick to construct and accurate but for large urban areas or even complete urban systems this is not the case. To create axial models of large cities it can take considerable time and the quality can vary greatly as consistency in method and accuracy will decrease as the area increases, especially if more than one person is involved in the mapping exercise.

Another element that cannot be overlooked is the relationship that the street network has to the surrounding built environment and its characteristics such as land use and socio-economic indicators. The axial representation of the street network is technically very difficult to reconcile with these factors due to the irregular spatial relationship axial lines have to their surrounding environment (fig 4). Through the application of road centre-line data that has a uniform relationship with the surrounding urban form it is easier to create a rich socio-spatial analysis that accounts for the urban system as a whole.

Figure 4 Comparison of axial network's (blue) and road centre-line network's relationship to built environment (ITN, red)

Owing to the specificity of axial maps they are not produced commercially or in the VGI sphere therefore they have to be constructed from scratch. Outside the academic realm this makes the process difficult to justify commercially, preventing space syntax analysis being used more widely as a design tool. Whilst the axial representation of space is widely understood within the space syntax community this is not the case in the wider realm of urban or social studies.

4.3 Evaluation Methodology

Three road network models for the Greater London region and one cut out of the Surbiton suburban area in south-west London were analysed using standard GIS statistical processes and Depthmap software (Turner, 2001) to examine their suitability for this research. The analysis is based around the visual interpretation of data and basic statistical tests. Detailed statistical analysis was not utilised due to the limitations of comparisons of fundamentally distinct datasets.

The three data sets were prepared so that they could be analysed in Depthmap but they were not simplified (i.e. extraneous lines were left in) and traffic management features were also not removed (see: fig 3) so that the 'readiness' for usage in space syntax analysis could be ascertained and their intrinsic representations of space could be clearly seen. The road centre-line networks for the suburban area were analysed using segment length weighted angular segment analysis at radii 800m, 2000m and *n*.

The axial network model was analysed without the segment length weighting at the same radii. The segment length weighting is necessary to compensate for the numerous small segments that road centre-line data have (Turner, 2007). The metric and topological step depth characteristics of the three network models were then evaluated followed by their connectivity.

Prior to the space syntax analysis within Depthmap the ITN and OSM network data were cleaned though a process of removing disjointed elements. (None were apparent in the ITN dataset, probably due to its high production standards). Within the OSM data there were numerous disconnected elements that had to be discarded prior to processing.

The following section describe the analysis undertaken in order to elucidate both the limitations of data not specifically designed for space syntax analysis, and the possibilities that different representations of city networks have for space syntax analysis.

4.4 Evaluation of Model Characteristics

The first aspect of the London-wide models that the evaluation brought to light was their radically different representations of the street network in relation to length and segment complexity. As shown in table 1, the axial model (which was transformed into a segment model within the proprietary software Depthmap) is both the shortest in total length and the simplest in network composition. The VGI data that OSM provides is the longest network length but only the second most complex in terms of number of segments. This is due to the network being simplified to a greater degree in regards to its capture of small details than the ITN and including paths and alleyways that the ITN data does not. The ITN provides the greatest detail of the structure of the urban network and the greatest resolution of angular change in the orientation of street segments. This is also illustrated in table 2 for the suburban area of Surbiton.

	OSM	ITN	AXIAL
Total Length (km)	29,700	26,027	20,039
Number of Segments	718,118	1,213,646	453,562

Table 1 Comparison summary of Greater London network characteristics

	OSM	ITN	AXIAL
Total Length (km)	1,456	1,197	1,075
Number of Segments	37,585	58,293	20,637

Table 2 Comparison summary of Surbiton network characteristics

A visual comparison of the three datasets was carried out within a GIS to allow the evaluation of their comparative network representations. As illustrated in figure 5 the differences that the models have is clear. The ITN data is the most consistent and detailed whilst the OSM data is a more generalised version without the highly detailed road feature details. The axial model on the other hand is a generalised but also radically different representation. This difference was of less consequence when analysis was made using axial maps – the set of fewest and longest lines that covered the network and minimised depth. When translated into street segments and particularly when used to analyse street network characteristics in relation to land use or other spatially detailed data, the apparent divergence from the street alignments is striking.

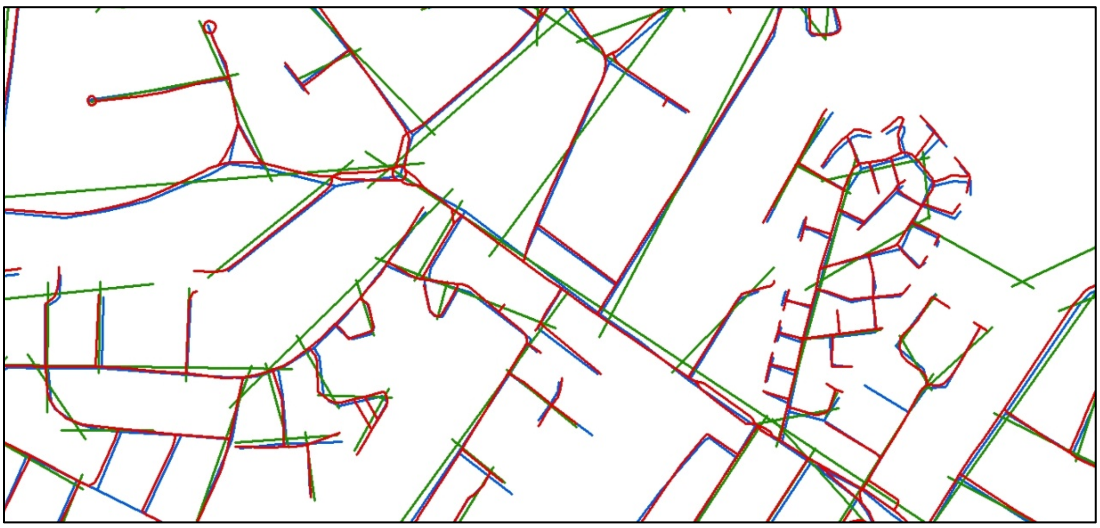


Figure 5 Overlaid image of axial (green), ITN (red) and OSM (blue) network models

This is especially interesting for increasingly common use of angular segment analysis in space syntax research. The axial model has been carried forward from the start of space syntax research and carried forward as the basis for modelling urban space in angular analysis. This analysis highlights the potential problem with doing so, as the angular representation of urban space in the axial model is a significantly deviation from street geometry. In an axial model a curved bend that moves through 90 degrees may be generalised to two segments with a singular angular change of 90 degrees whilst a road centre-line might represent this as 10 small angular changes of 9 degrees each. How this change in representation impacts on the analysis outcomes needs a specific study to understand the precise impact of different street network representations on angular segment analysis. Evidently, road centre-lines present the most accurate representation of angular change in urban space and therefore potentially the most accurate model for movement based on angular change (fig 7), although they have a different set of limitations, as shown in the following passage.

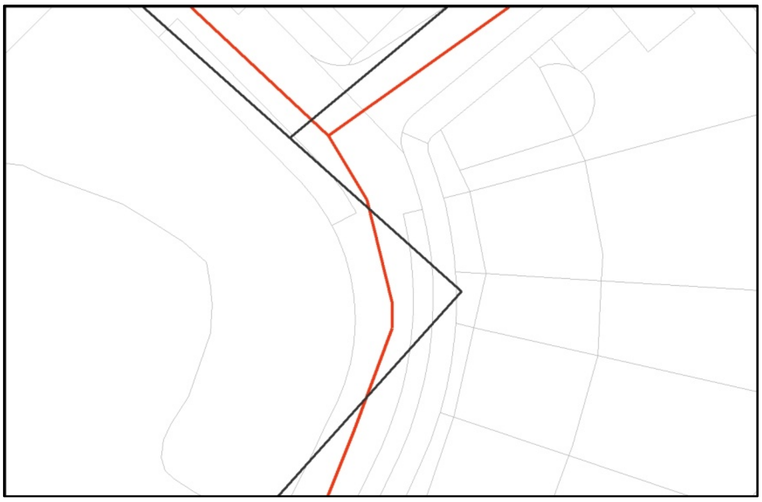


Figure 6 Angular representation of street geometry (ITN-red, axial-black)

4.4.1 Evaluation of Choice and Integration Network Measures

Figures 6, 7, and 8 show the results of the Depthmap analysis of the three network models for choice at radius *n* for the area of Surbiton (town centre is indicated by arrow in fig. 6). These images clearly illustrate the same principal network structures are being identified as having the highest choice value, with the exception of the footpath route along the river in the OSM network model (Fig 8). This element is not present in the other network models so it cannot be included in their respective analyses. The inclusion of pedestrian-only routes also highlights the existence of a 'deformed wheel' pattern – indicating the presence of a primary route structure, a fundamental concept in space syntax research (Hillier, 1996) - that is more intricate and apparent than in the other two network models. This may lead one to hypothesise that the primary network structure of the city can be seen most clearly when all possible network elements are considered. The visual similarity of the results indicates that although they are radically different representations, as is their purpose of representation, the space syntax analytical tools can interrogate the data effectively. In figure 7 showing the ITN network it also emphasises the main trunk (vehicular) road, confirming the ITN representational characteristics as being road-centric.

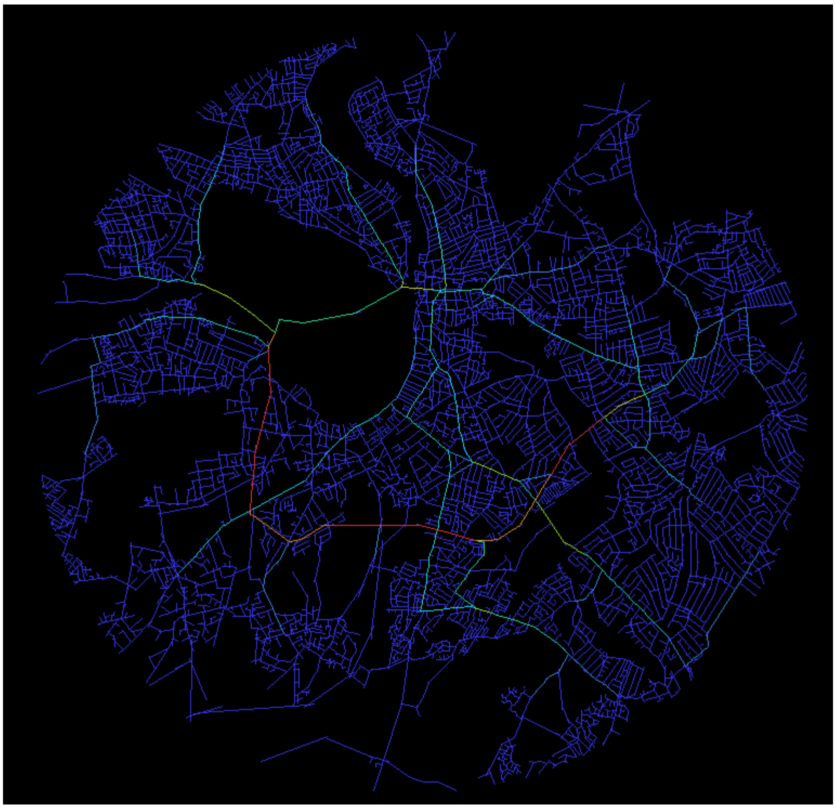


Figure 7 Surbiton axial network model analysed at radius n

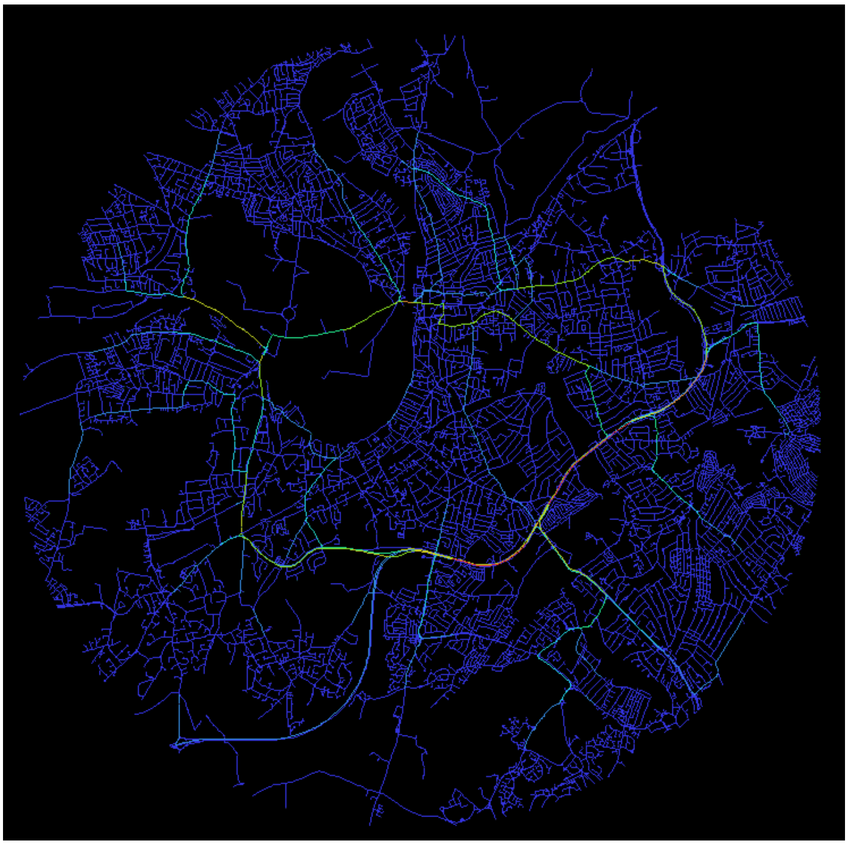


Figure 8 Surbiton ITN network model analysed at radius n

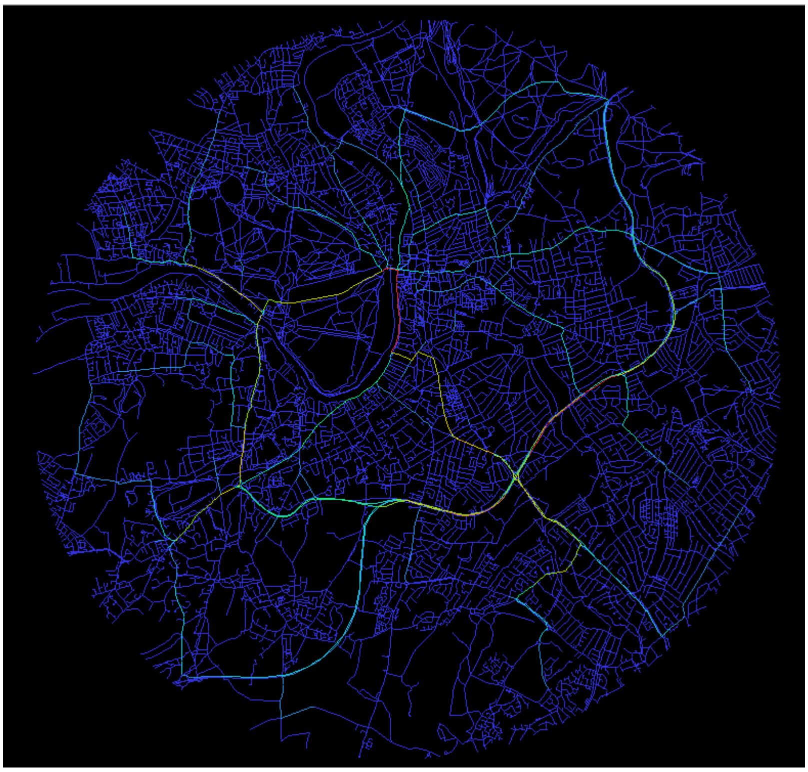


Figure 9 Surbiton OSM network model analysed at radius n

Figures 9 to 14 show the results of the analysis for choice at radii 2000m and 800m.The results from the 2000m analysis show that at the smaller scale the axial model shows markedly different results to the ITN and OSM models. The axial model defines peaks of choice values more clearly whilst the road centre-line models show a more diffuse gradient of choice values across the network. The reason for this could be the disjointed network structure that the road centre-line data has due to traffic management features (fig 3) or it could be the result of the nuanced representation of angular change in the network that the axial model does not capture. The axial model also does not highlight the choice importance of the arterial road that encircles the south-east of the area. This is a major network feature that is of significant structural importance in the area and for through-movement of traffic.

The 800m choice measures in figures 12 to 14 further illustrate the differences between the axial model and the road centre-line models. The axial model identifies the small centres clearly whilst the ITN and OSM models pick out the centres in a more diffuse way whilst still highlighting elements of the arterial road network and junctions that the axial model does not.

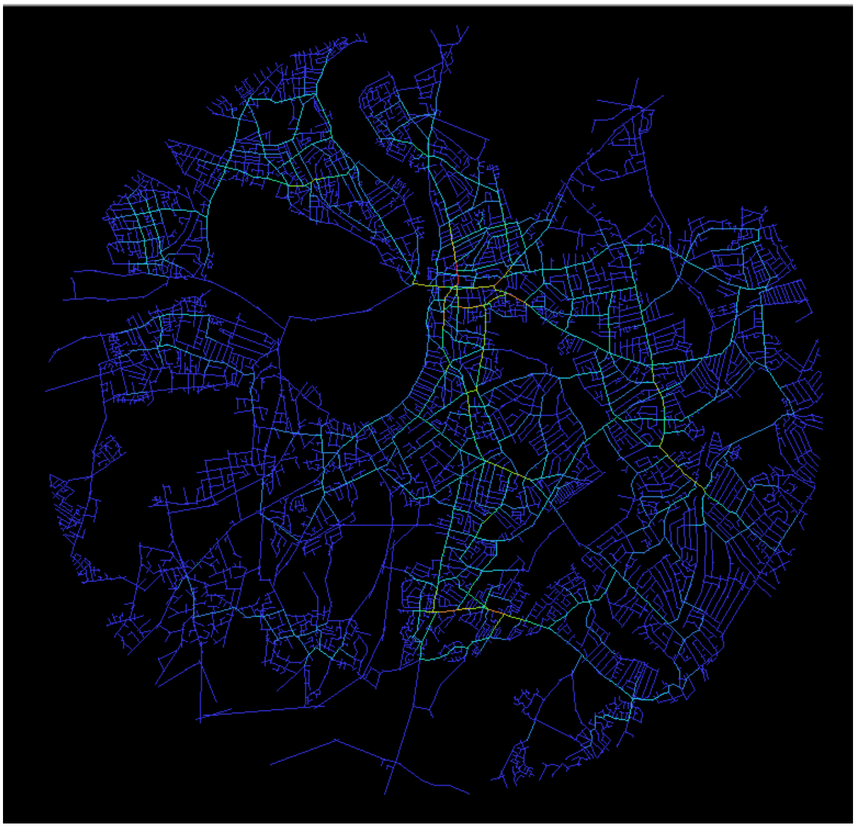


Figure 10 Surbiton axial model choice radius 2000m

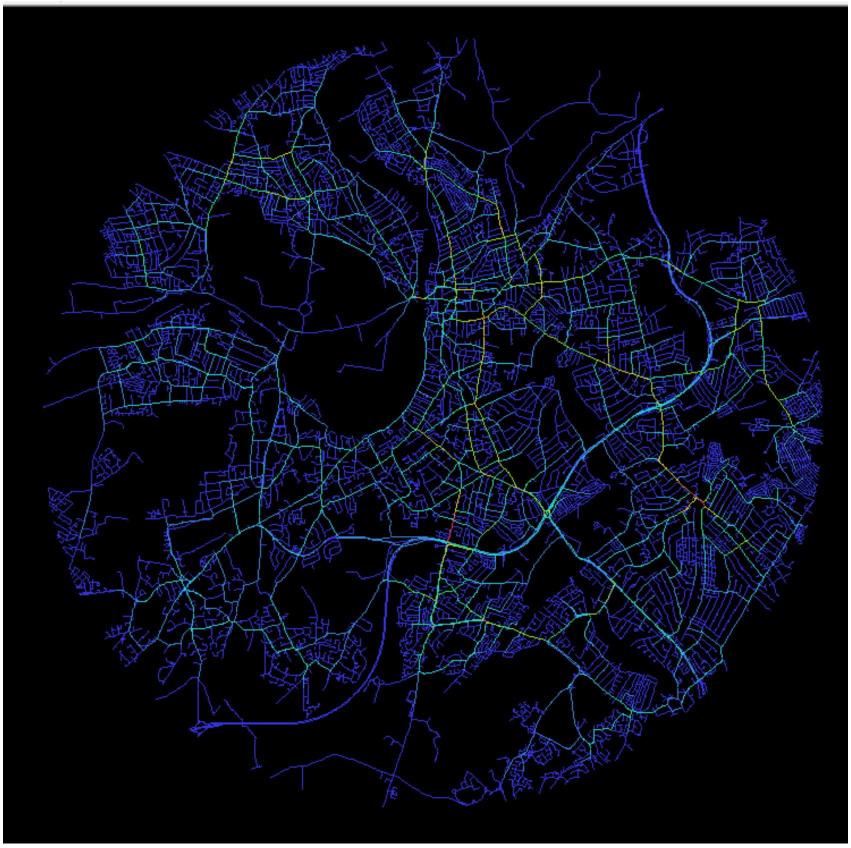


Figure 11 Surbiton ITN model choice radius 2000m

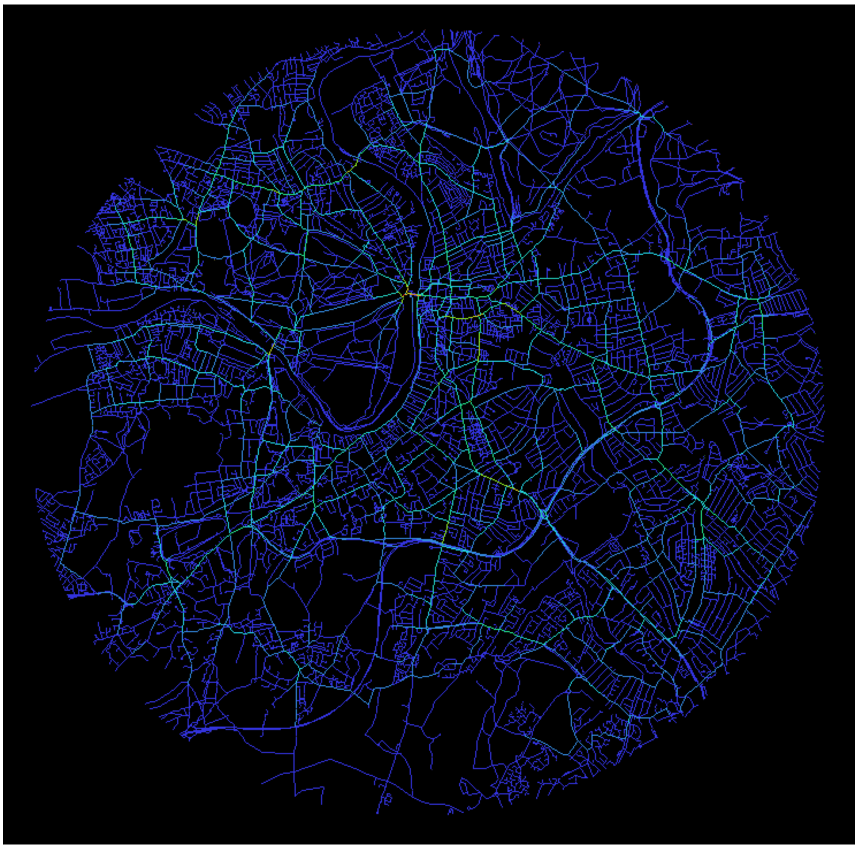


Figure 12 Surbiton OSM model choice radius 2000m

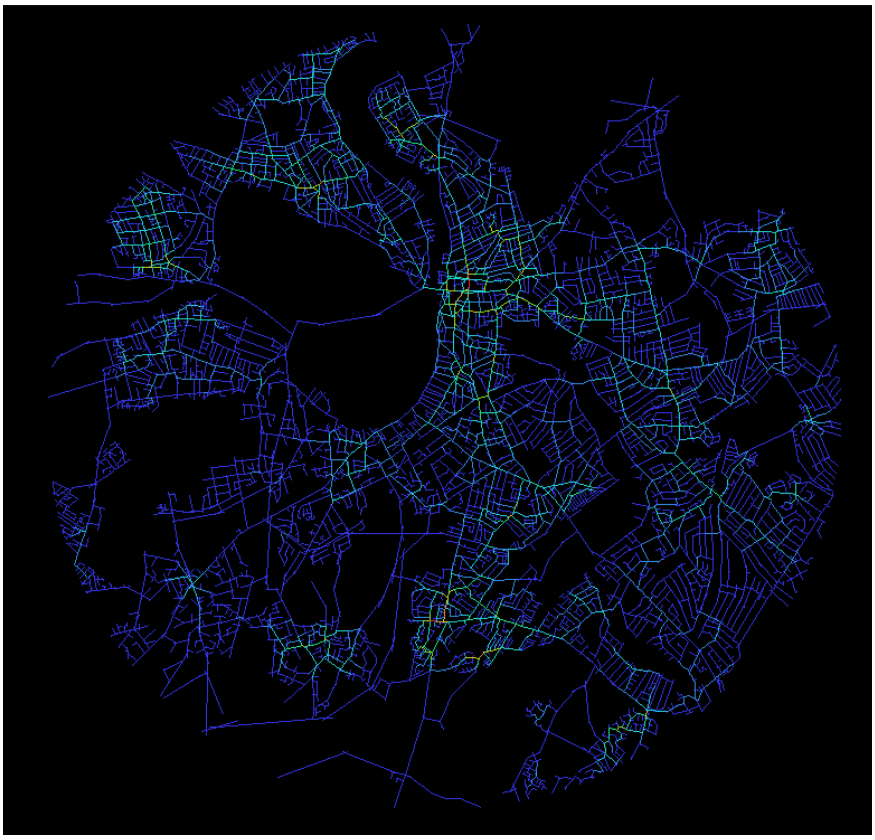


Figure 13 Surbiton axial model choice radius 800m

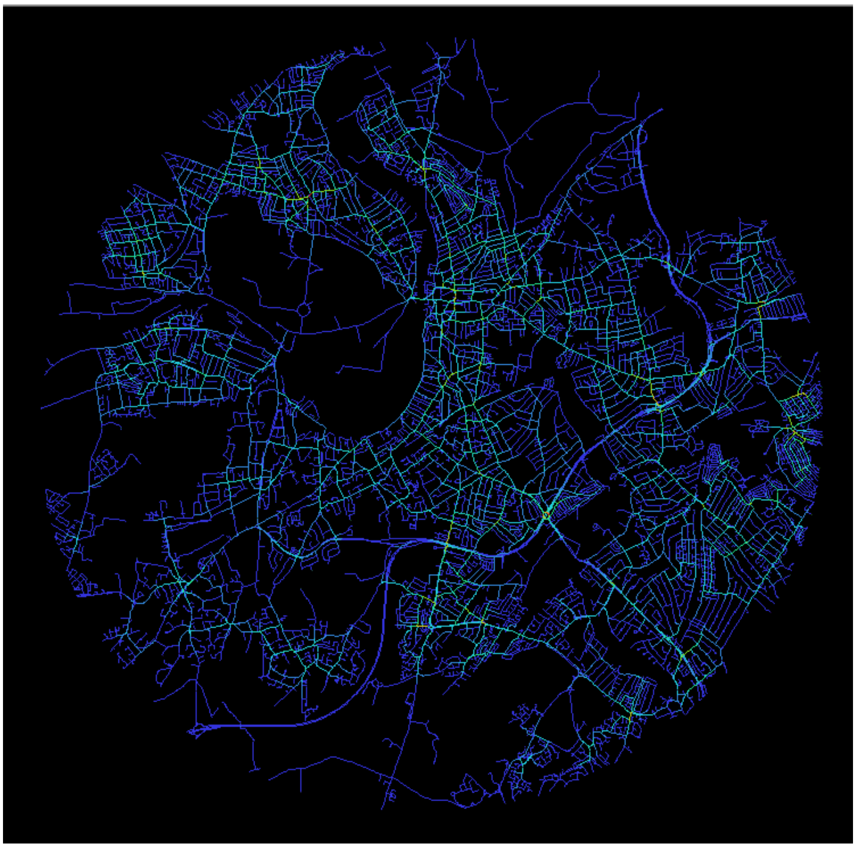


Figure 14 Surbiton ITN model choice radius 800m

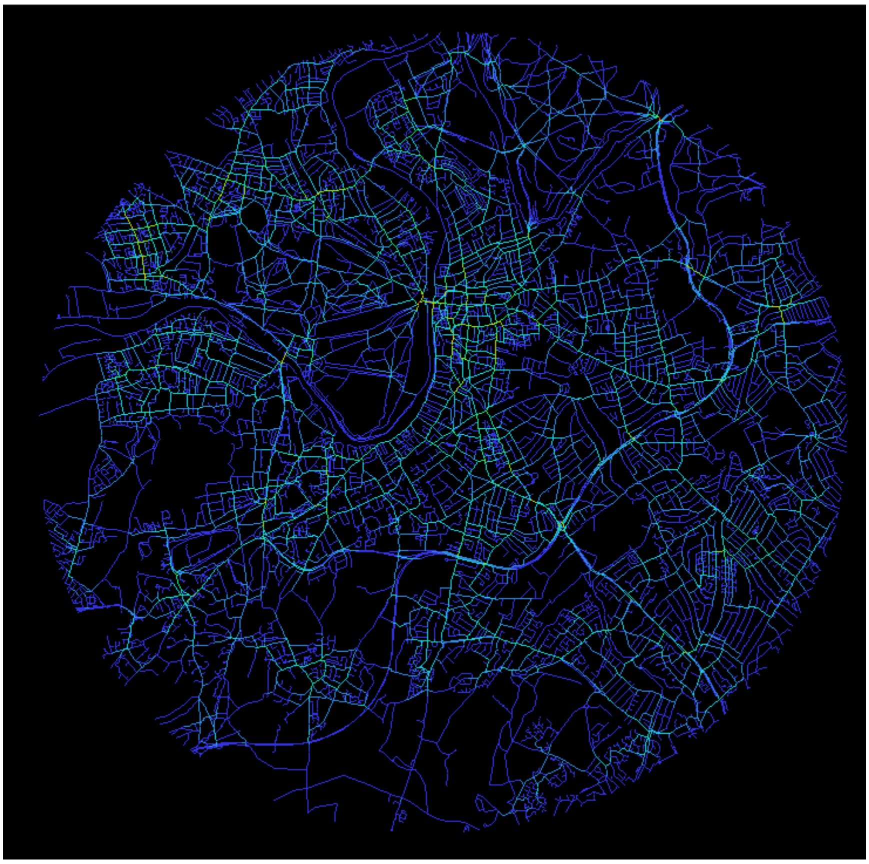


Figure 15 Surbiton OSM model choice radius 800m

Figures 15 to 18 show the results of the analysis of integration at radius *n* in Surbiton using the three network models. The results again clearly show that the selection of network model has significant impact on the results. Similarly to the choice analysis the ITN network emphasises the arterial road as the most integrated element in the network. The axial model also demonstrates this to a lesser degree with a more circular distribution of high integration across the area. The ITN network is demonstrating a highly car centric view of the network.

The OSM network shows the most significant difference in regards to the structure of integration in the network. Whilst the arterial road is important, the centre of the area is strongly linked to it and exhibits high levels of integration across the network as a whole. The extra network elements of paths and alleyways are likely to have caused this as it will increase the density of routes in the town centres and create a more highly connected network. A comparison of the OSM network to the ITN network illustrates how the representation of the network affects the analytical outcomes. The holistic representation of the network of all routes that OSM represents highlights the space that people will move through as much as the spaces cars will. The combination of fine grain detail of small local routes and global routes creates a richer picture of the structures of integration, but also potentially reduces the distinction between localised and wider-scale of potential movement patterns.

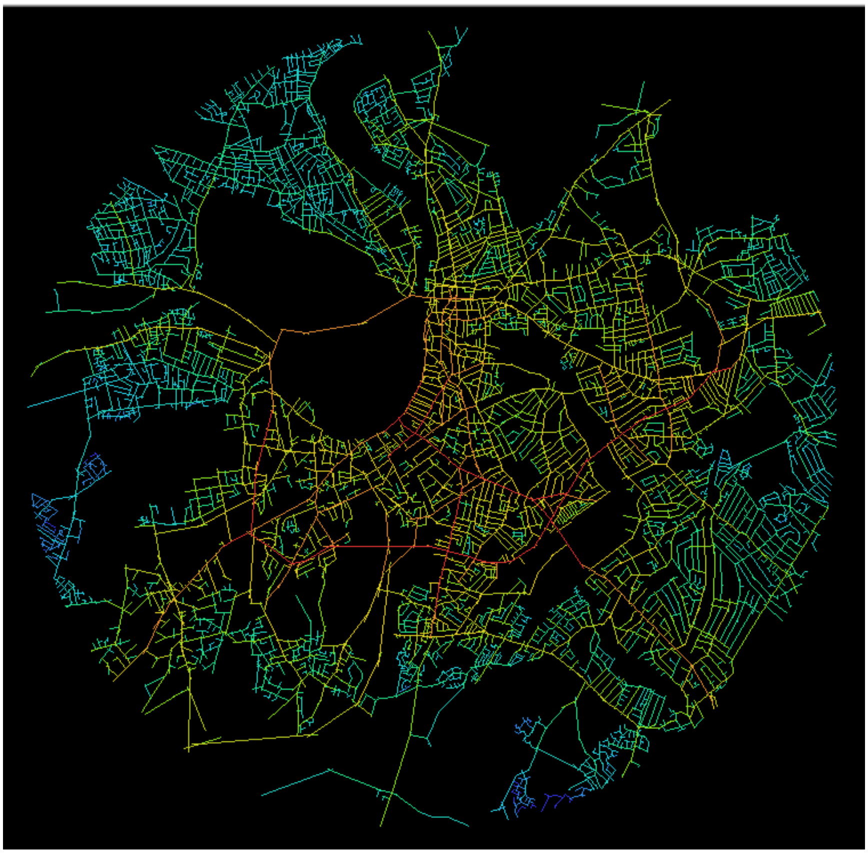


Figure 16 Surbiton axial model integration radius n.

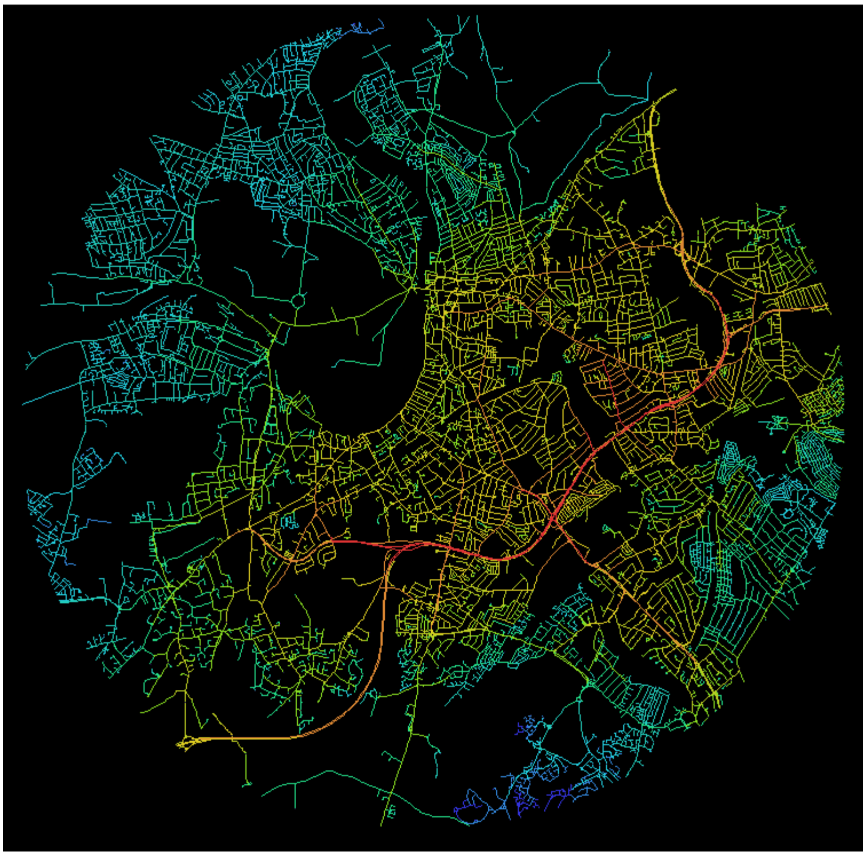


Figure 17 Surbiton ITN model integration radius n.

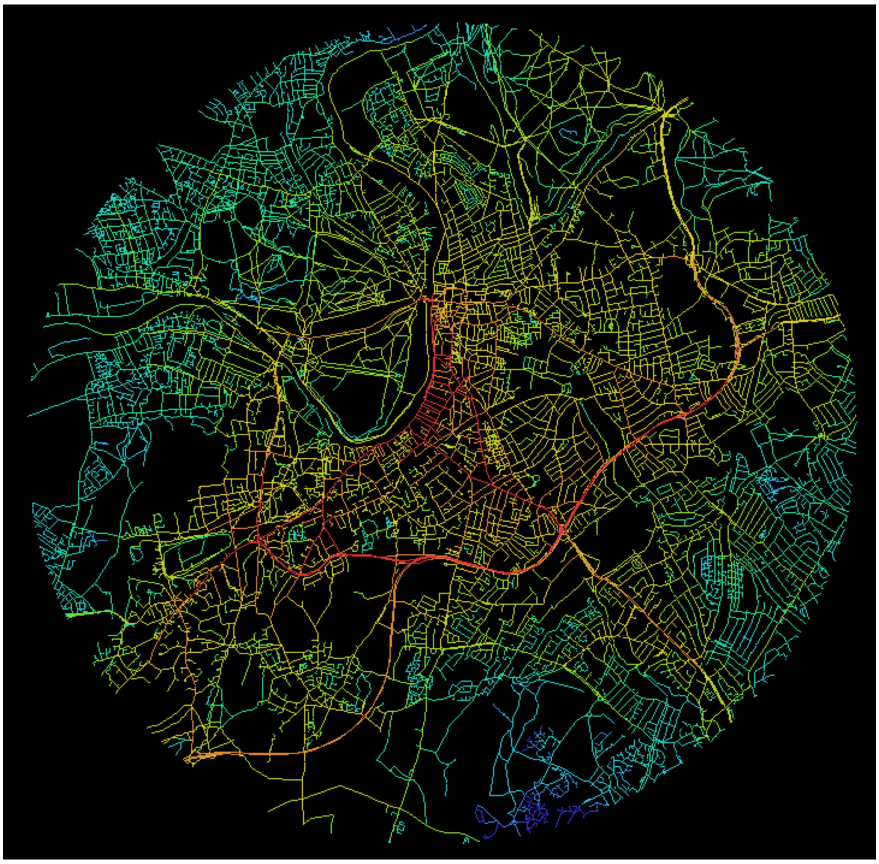


Figure 18 Surbiton OSM model integration radius n.

Integration at the local radius of 800m as shown in figure 19 is similar to choice at 800m radius for the ITN network. The junctions of the major arterial roads maintain their importance to the local area whilst the roads connecting them do not. This makes sense spatially as they are the access points for the local areas to the wider network. The ITN model also shows distinct local areas similarly to the axial model in figure 18. The axial model clearly identifies and separates the local areas from one another and identifies them as local units without detecting the larger structural elements such as arterial road junctions as of significance to the 800m radius of analysis.

The OSM network in figure 20 shows a far more incoherent picture than the axial or ITN models. The centre in the north west of the network is more integrated than any other part of the network. This is likely to have arisen from the inconsistent mapping of the different areas or the quality of the mapping leading to multiple lines intersecting where in reality they do not.

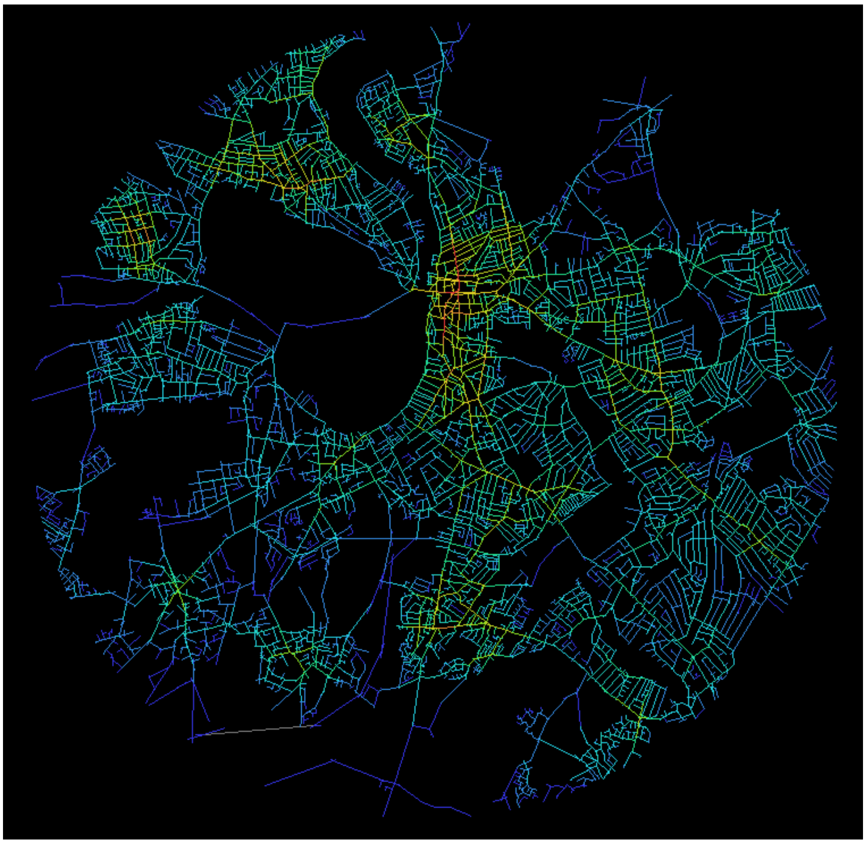


Figure 19 Surbiton axial model integration radius 800m

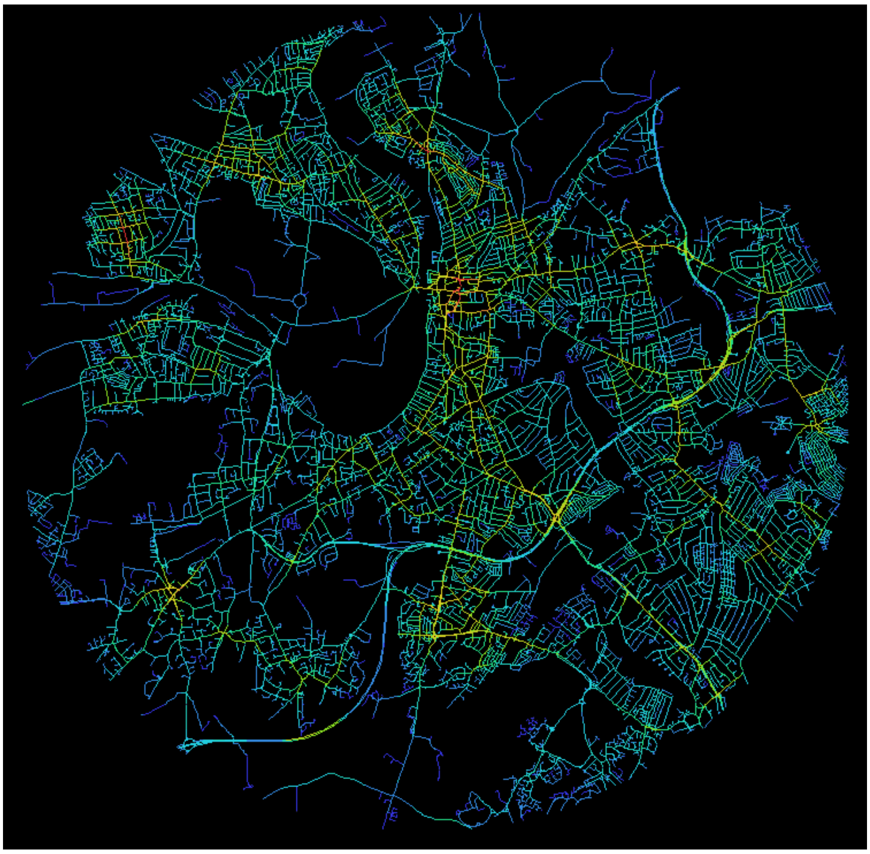


Figure 20 Surbiton ITN model integration radius 800m

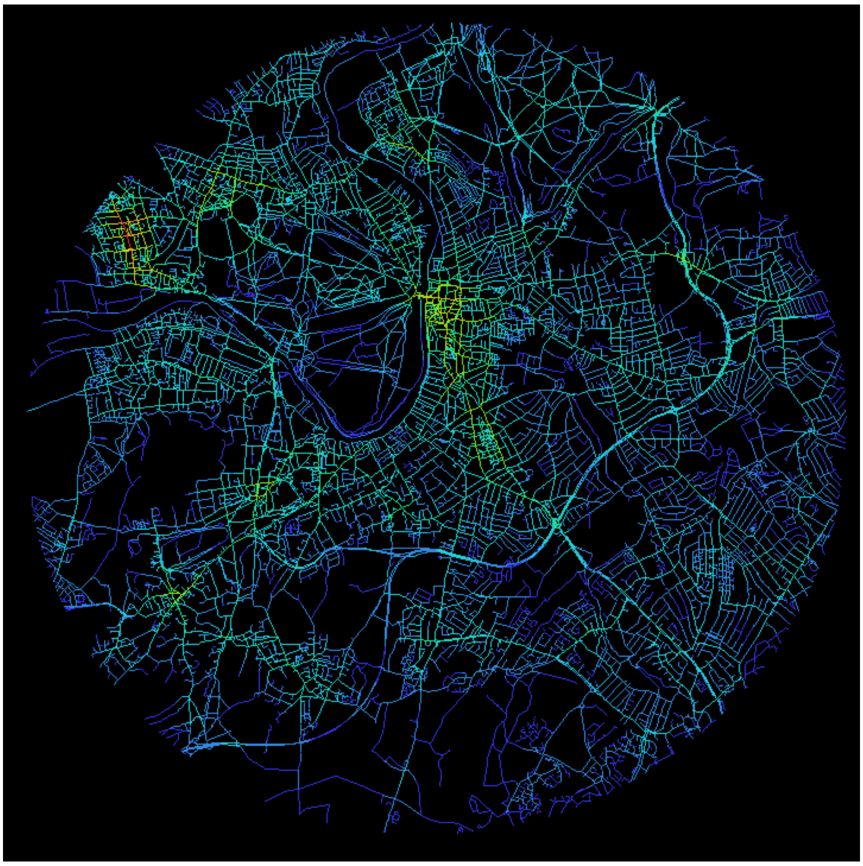


Figure 21 Surbiton OSM model integration radius 800m

4.4.2 Evaluation of Other Network Properties

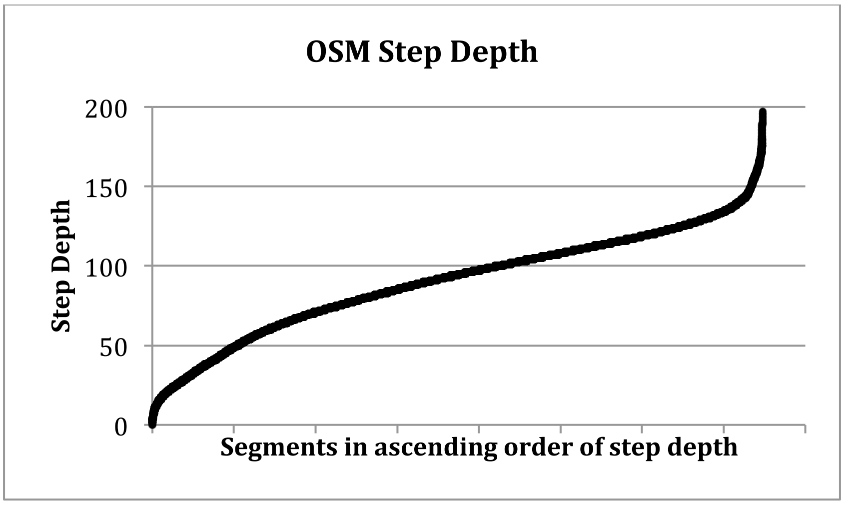
Table 3 presents the topological step depth characteristics of the OSM, ITN and axial network models. The measurements in all three networks were taken from the segment in the centre of the network directly outside Surbiton railway station. Here the greatly differing complexity of their segmental representations is shown.

Topological Step Depth	OSM	ITN	AXIAL
Mean	90	197	49
Median	94	204	50
Maximum	197	422	90
Mode	106	224	44

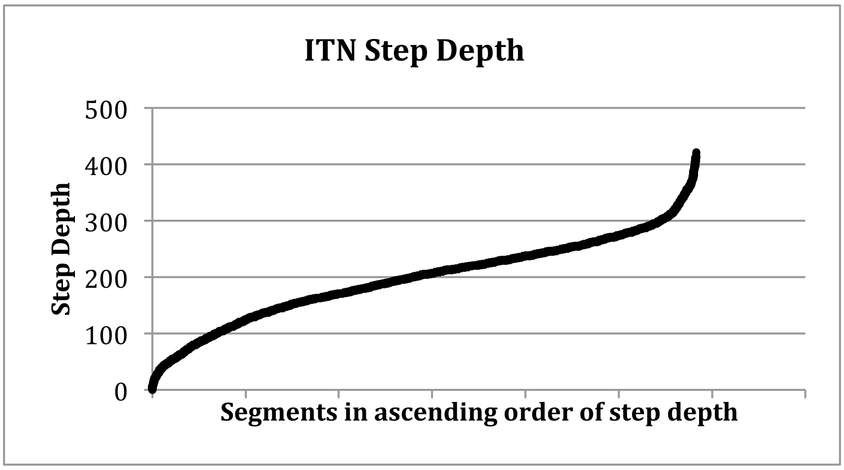
Table 3 Topological step depth characteristics of network models

The ITN network model of the road network is made up of a far greater number of segments. The average step depth for the ITN model is more than twice the OSM model and four times greater than the axial model. This highlights the intricacy of the ITN model that attempts to represent the smallest changes in orientation of the street structure through the usage of many more segments to describe the network structure. The similarity of the relationship between values in table 3 is also relevant. All three models share similar relational properties between their respective mean, mode, median and maximum.

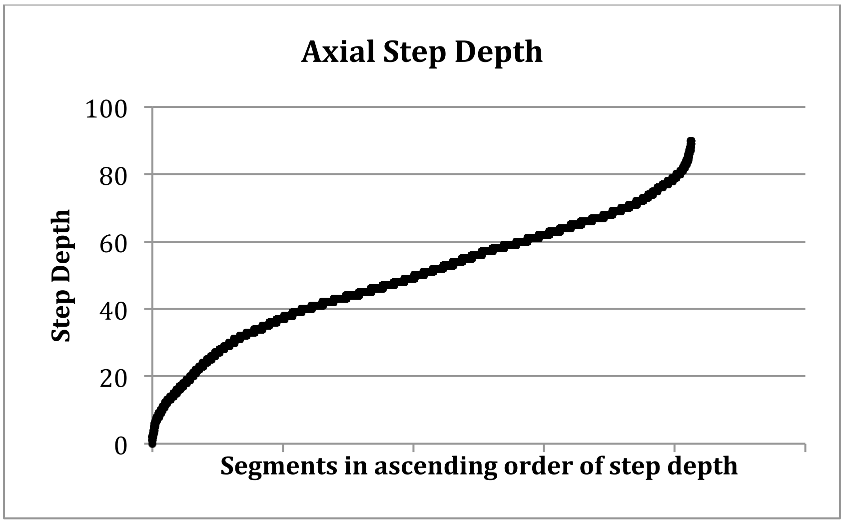
Although the step depth values are very different between the models they all have a common structure to the distribution of the step depth values. Graphs one to three show the step depth value of every segment in each model sorted according to their step depth value. These graphs all show the same shape of distribution for the values. This highlights the similar structural properties that the network representations have. The three models represent the street network in different ways yet the structure of that representation is similar across all three models regardless of the detail or purpose of their representation.



Graph 1 OSM step depth distribution



Graph 2 ITN step depth distribution



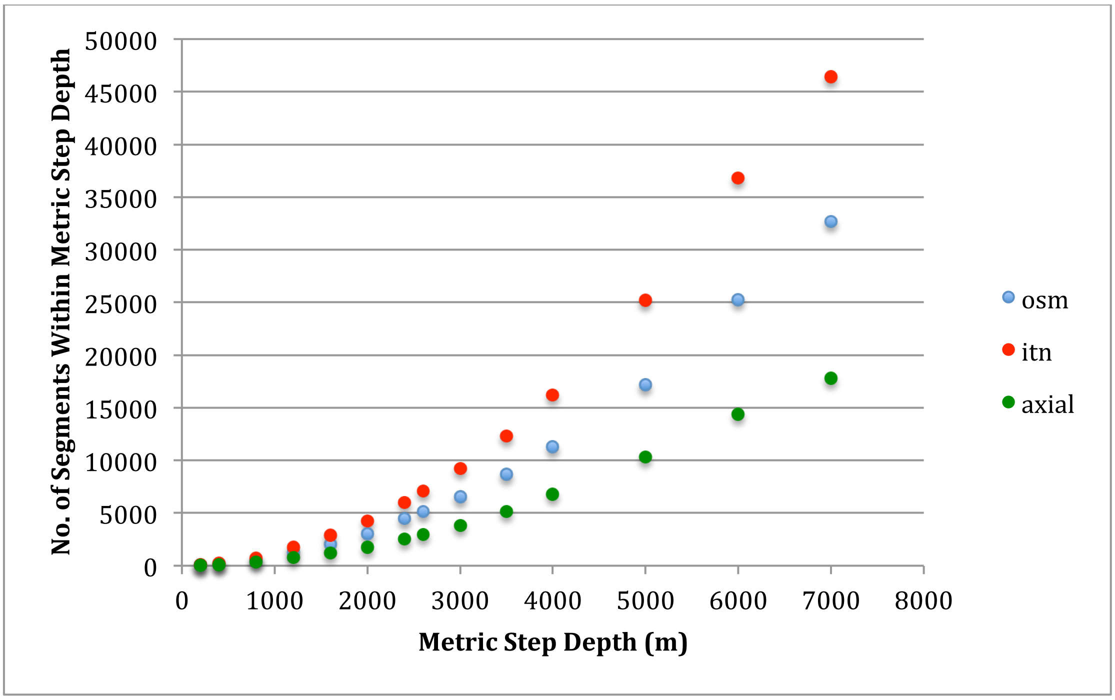
Graph 3 Axial step depth distribution

Metric step depth analysis further illustrates the similarities and differences in the network representations. In table 4 the number of segments that are within a specified metric step depth are shown. Again we see that the difference between the three networks in terms of number of segments is very large. At 7000m the ITN model is comprised of 46,442 segments whilst the axial model has 17,812 segments.

Metric Step Depth (m)	**OSM**	**ITN**	**AXIAL**
200	54	135	18
400	159	255	77
800	518	706	325
1200	1265	1747	755
1600	2074	2905	1210
2000	3036	4265	1774
2400	4459	6025	2523
2600	5139	7066	2984
3000	6559	9232	3824
3500	8647	12337	5178
4000	11274	16220	6776
5000	17167	25196	10292
6000	25248	36813	14403
7000	32669	46442	17812

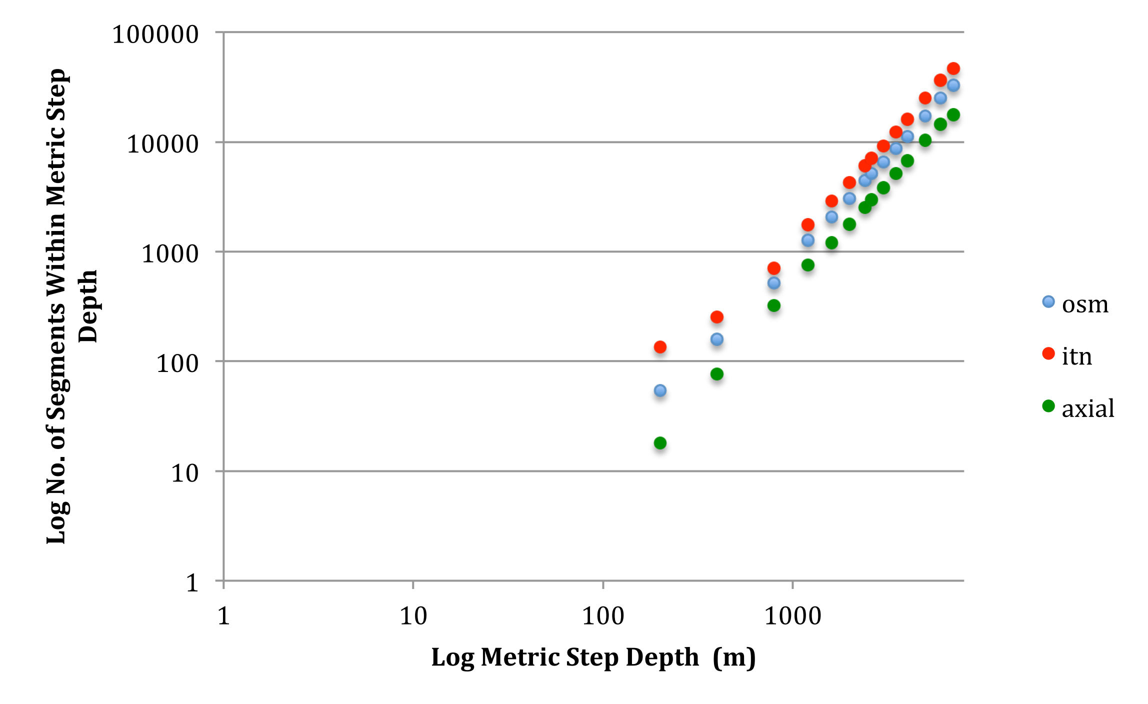
Table 4 Total number of segments within specified metric step depth for each network model

Whilst the raw numbers show a very different image of the three networks they are in fact very similar. Graph 4 shows the values of table 4 plotted as a graph.



Graph 4 Number of segments within specified metric step depth for OSM, ITN and axial models

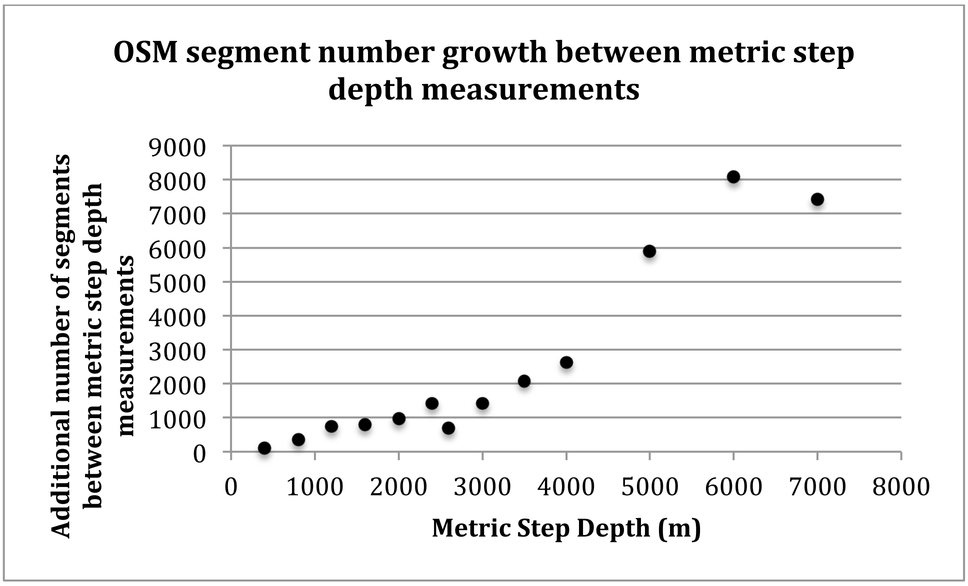
Graph 4 shows all three models display the same structure to the growth of the complexity of the network over the space that they cover. It shows that the level of detail in which they render the street network is consistent across scales. This is better shown on a log-log plot of the values where the similarities between the models' growth pattern is clearer, as shown in the graph 5.



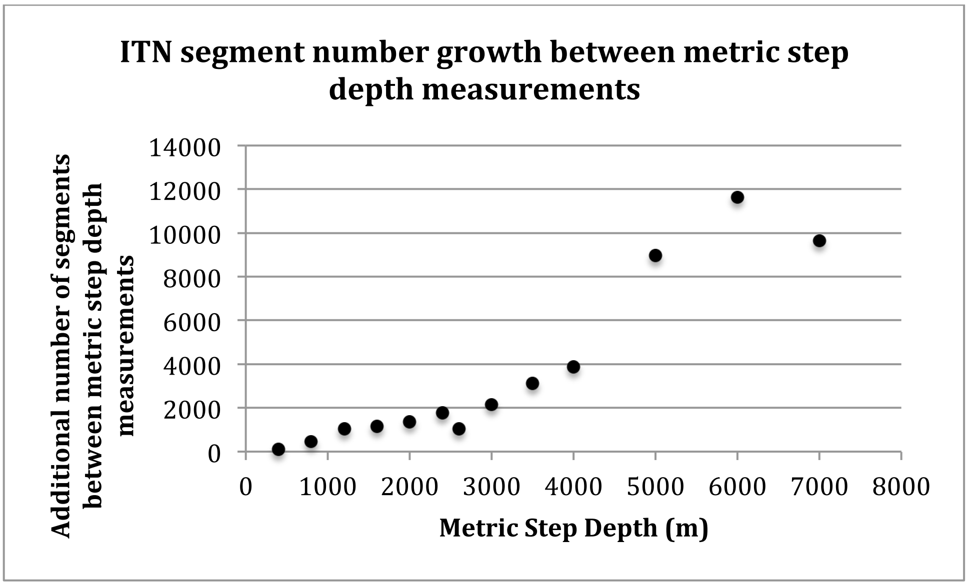
Graph 5 Log-Log plot of number of segments within specified metric step depth radius for OSM, ITN and axial models

This indicates that the OSM, ITN and axial models all scale over space in a consistent fashion. This might indicate that as representations of the street network they are in fact the same and do not represent a fundamentally different structure of city space when using a road centre-line segment model. The road centre-line representations of the OSM and ITN models would be expected to be different to the axial model, but this is not the case. The differences that remain are the resolution of detail of the street structures (as shown in the step depth analysis) and the detail in the geometric representation of the relationship between street segments. In both these cases the ITN is the most detailed account of the structure of the street segments and the geometric relationships between segments, OSM is the second most detailed and the axial model is the least detailed.

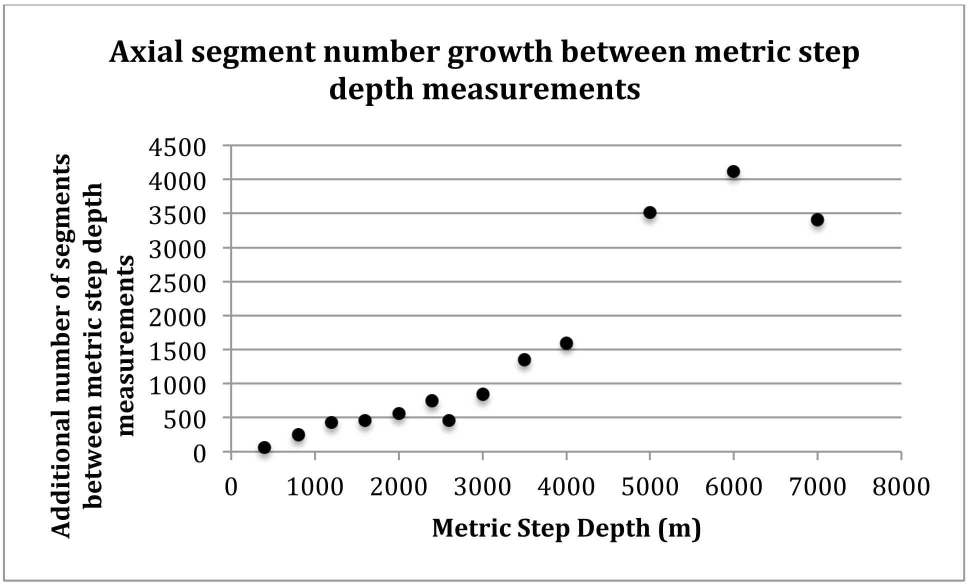
The similarity of how the network representations scale over space is further highlighted by graphs 6 to 8, that show the number of segments that are added in each model between each distance in metric step depth that was measured, as can be seen the segment structure of the street network grows in respect to metric step depth in a nearly identical fashion in each model.



Graph 6 OSM change in segment number between metric step depth measurements

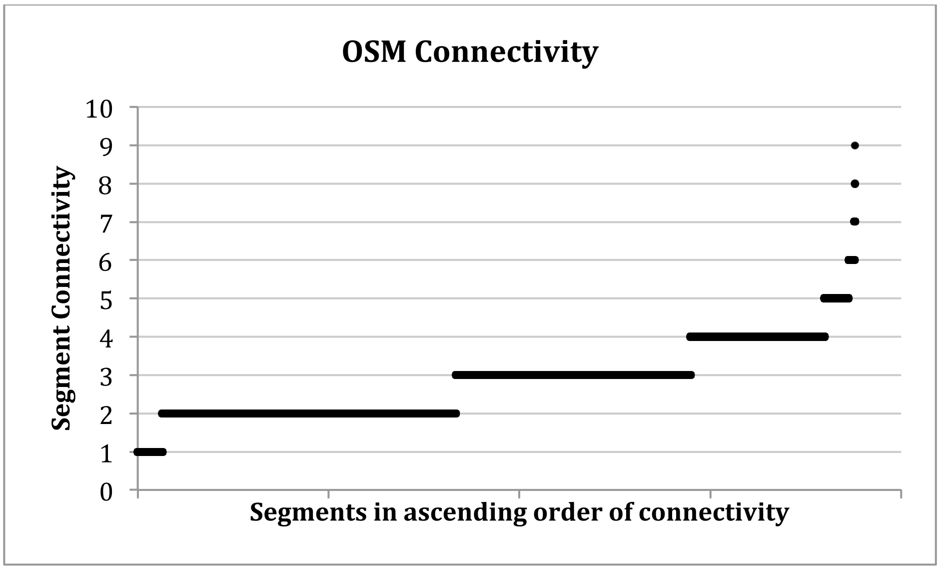


Graph 7 ITN change in segment number between metric step depth measurements

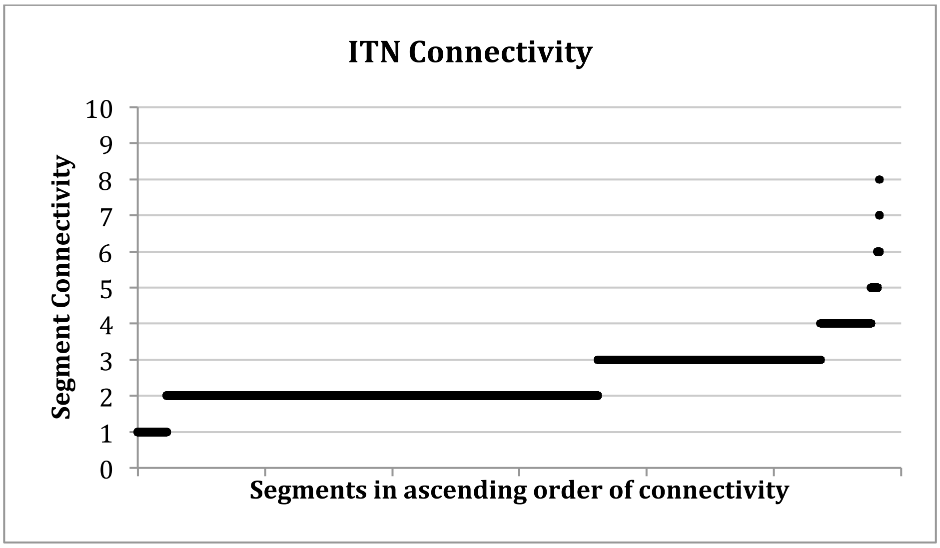


Graph 8 Axial change in segment number between metric step depth measurements

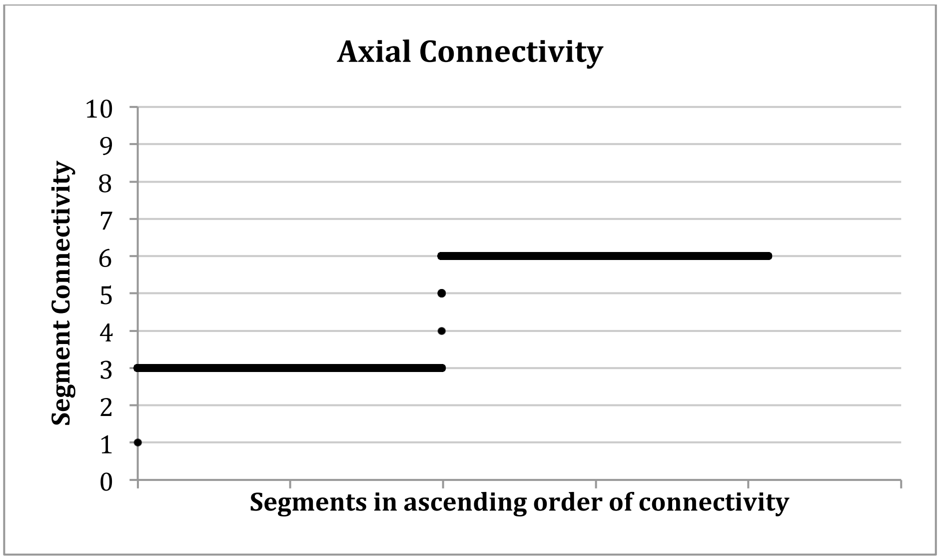
Graphs 9 to 11 show the connectivity of all segments in each network model. From these graphs it can be seen that the OSM and ITN have a very similar distribution of connectivity, in both cases the connectivity value of 2 is the most common and overall they show a normal distribution of values. They also demonstrate a coherent structure to the measure of connectivity across the whole network. In contrast, the axial network model does not show a similar distribution of connectivity values. With a few exceptions all the segments have connectivity of 3 or 6. Whilst the step depth and metric step depth show that all three models are very similar, the connectivity values show that in this regard the axial model has a very different structure. The axial network does not have coherently structured connectivity across the network. The segmented axial model is structurally similar to the OSM and ITN road centre-line models but it does not have the same relational structure between segments as the road centre-line models. Again this points to the possibility that the axial models' account of relationships between segments is very different from road centre-line models and possibly problematic for angular segment analysis.



Graph 9 OSM connectivity structure



Graph 10 ITN connectivity structure



Graph 11 Axial connectivity structure

4.5 Street Network Data Evaluation Discussion

The results of the analysis reflect the fact that the ITN network is primarily a representation of the *road* network; whilst the axial and OSM models explicitly set out to include pedestrian networks, thus constitute a representation of the *street* network. This was borne out in the analysis where the main road structures within the ITN data maintained their importance across the scales of analysis (figures 10-11 and 13-14). This in itself is not unproblematic as it raises the question as to whether these features should be indicated to be relevant to small scales. It could be hypothesised that they remain relevant as they are access points to a non-local network and in effect they represent an end point to a journey within a local network that then continues on within a different network structure.

The main problem with the ITN road centre-line data is the need to remove features such as traffic islands (fig 3) that create breaks in otherwise continuous lines. For space syntax applications such traffic management features are incongruent with the required description of the street and the result of including such features is that choice and integration values are distorted unduly. Apart from this issue the ITN network is the most consistent and for the purposes of this research, forms an ideal basis for the analysis of the road network. It is also the most nuanced account of the geometric properties of the urban network - which may be of benefit to angular segment analysis.

The UK national mapping agency has also now recently released an Urban Paths network dataset to supplement the ITN road network data. This extra dataset includes all pedestrian and cycle routes through the urban fabric. This shows the growing appreciation that the network representation of London that has been the norm for many years is not a complete image, but a partial one and a representation of the normative view of the street system as serving the car. With the creation and release of this new dataset the urban system will be able to be seen and analysed as a complex interplay of car and pedestrian movement through all the possible routes that the network affords rather than primarily an automotive road network that national mapping agency data has afforded thus far. Indeed, it was integrated into the model used for this research project.

The OSM dataset is more problematic for usage in space syntax analysis as there is a lack of consistency in the accuracy and coverage of the data. Whilst it can theoretically be used for analysis in urban areas that have been well mapped, it cannot replace official mapping data nor can the results be relied upon unless the dataset is comprehensively checked to be a complete representation of the area being studied. The main use that OSM data provides is the supplementation of official data for small local areas. It would be particularly important as a supplement to official network maps that exclude pedestrian pathways (as has been the case in the UK until recent times). It may provide new information that is not officially recorded and give insight into the local area from the perspective of citizens rather than government agencies. The fact that this includes non-road structures and that it is created by people on the ground or viewing the city planimetrically from aerial images and they choose to include non-road network elements, demonstrates that the individual’s understanding of the city is not that one that focuses on the road as the primary and sole space of movement potential in the city. This can be used as an indication as to what should be included in a network representation from the perspective of those who inhabit the space under analysis.

The axial model of urban space is a separate entity to the other models. It does not seek to replicate reality 1:1 but to represent a unique aspect of urban space. This has been proven to be effective in numerous studies but with the widespread usage of angular analysis and dual analysis of the network and its surrounding environs in space syntax research, it is evident that the axial model needs to be tested to verify its utility for segment angular analysis. The analysis of the topological and metric step depth clearly shows that as a representation of space in segmented form the axial model is not fundamentally different to the OSM and ITN models. They all scale across space in a similar fashion and do not represent fundamentally different spatial structures; they do however represent the geometric and segmental relationships very differently. The connectivity analysis highlights the differences between the models' segmental relational structure. The axial model is not as clear in this regard and may not be a reliable representation of segment connectivity. The road centre-line representation may well be a more accurate representation of the segmental structure of urban space.

Having established that the ITN based model would be used for the research, a method needed to be found to create and compare between the contemporary model and the three historic periods studied. This is described in the following section.

4.6 Historic Street Network Reconstruction Methodology

In order to accomplish the research a range of practical methodologies were used in the management, creation and analysis of data. To manage the geographic data a geographic information system (GIS) was used where all the contemporary and historic data can be stored, manipulated and analysed. Figure 22 diagrammatically illustrates how the contemporary and historic data is compiled as layers to create a chronology of London wide mapping. The GIS system chosen was ArcGIS software.

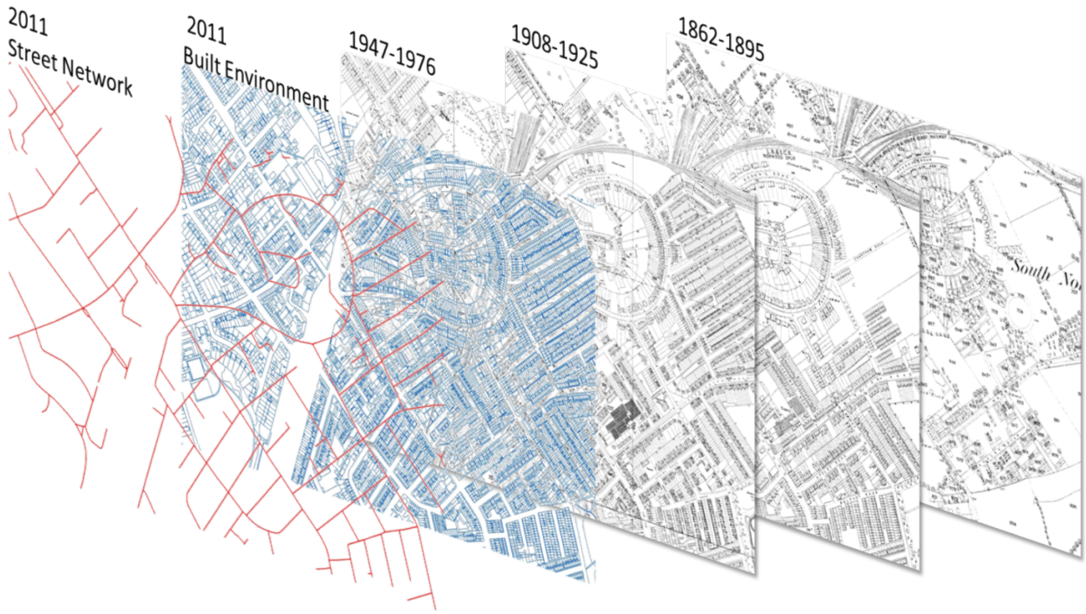


Figure 22 Data compilation within geographic information system (GIS).

In order to create a time series of network representations of London's street and footpath network at the four historic periods between 1862 and 2011 a method called 'cartographic redrawing' (Pinho and Oliveira, 2009, Pinho and Serra, 2011) is employed. This is necessary due to the space syntax network analysis techniques requiring a vector line based representation of the street network in order for the analysis to be carried out and the historic map data only being available in raster image format. Cartographic redrawing is a method that allows for the non-destructive creation of chronologies of urban morphologies.

The process is carried out from the contemporary backwards with the most accurate contemporary vector street network data forming the basis of all the historic street network representations. The contemporary vector line data is overlaid on the historic mapping for the first preceding period under investigation (in this case 1960) (Figure 23) and all sections of road and footpath are deleted that are not present in that period so that the street network matches the previous period. This is repeated for each preceding historic period being studied (1910 and 1880).

Figure 23 Contemporary ITN Road Network overlaid on c.1960 1:2,500 scale Ordnance Survey map

This process creates an individual layer for each period but preserves a common identity for the line parts across all periods so that each period can be compared and analysed against one another easily, quickly and accurately (Figure 24). It also minimises the time that is required for the process as deleting line segments is considerably faster than drawing street lines from scratch. The contemporary street network dataset used is the Ordnance Survey Integrated Transport Network (ITN), as discussed in the previous sections. This is a road centre-line dataset that captures the central line along a street. The map data that is used as the base mapping which will be used in the cartographic redrawing process is the 1:2500 Ordnance Survey Country Series historic mapping. The three historic time periods studied were: c.1880, c.1910 and c.1960. These periods were selected as they provided almost complete coverage for the London region within the M25 in the shortest range of years around these dates of any historic mapping datasets. This ensures that when the areas are compared they represent the same time period in each case. It also provided for any future comparative research to be carried out on other parts of London using this base mapping, due to the coverage of the whole of London within a similar time frame.

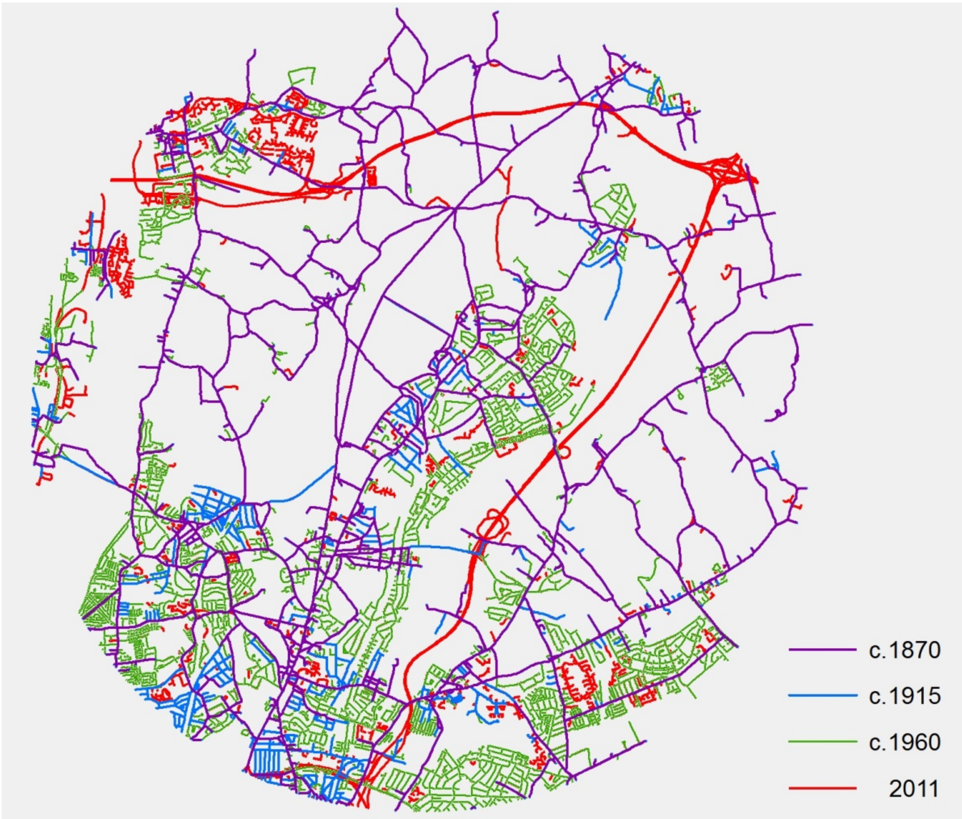


Figure 24 Cartographic re-drawing example: c.1870 (purple), c.1915 (blue), c.1960 (green), 2011 (red). Loughton suburban case study area road network.

The size of the area covered was 6km beyond the town centre of each of the four case studies (Figure 25), which as will be explained below, ensured a sufficiently large contextual area to be studied at large space syntax scales of analysis.

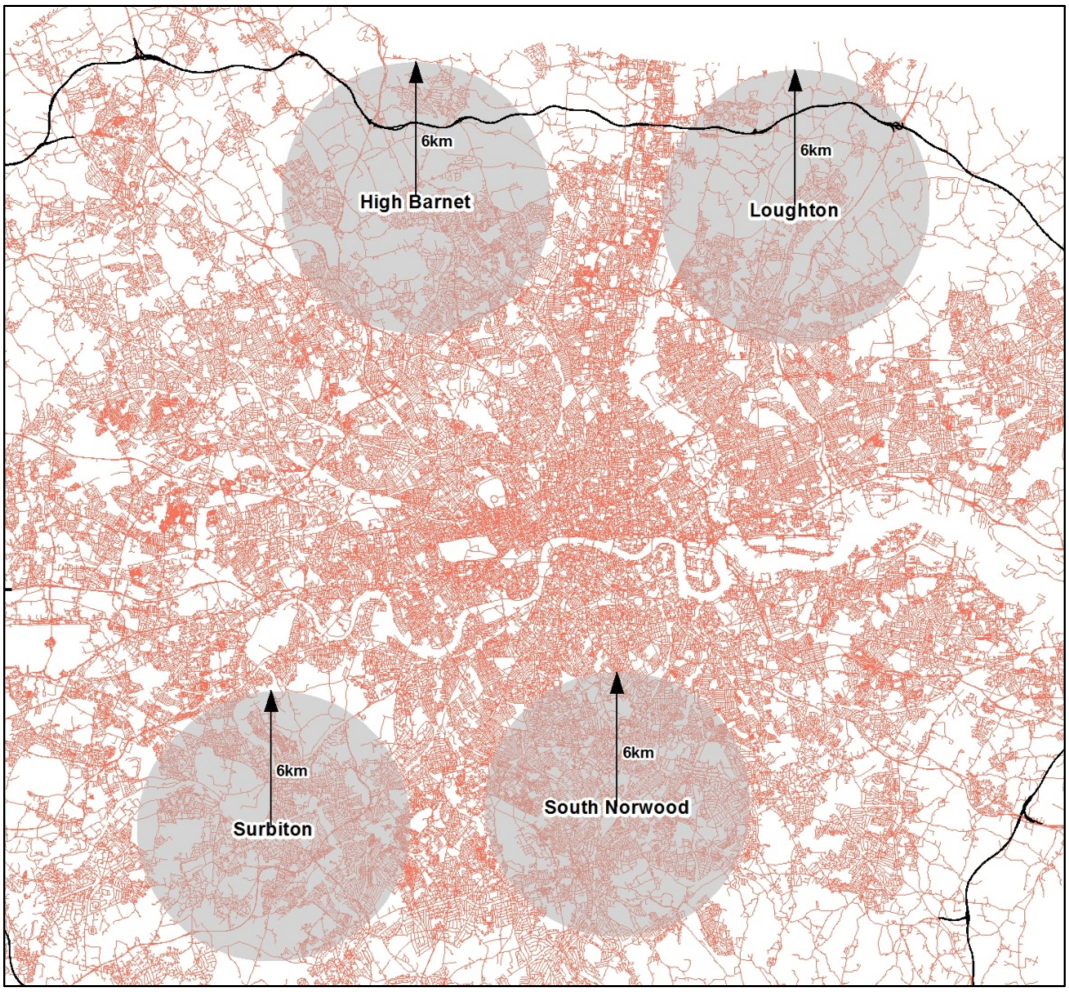


Figure 25 Detailed building footprint reconstruction 6km around each suburban case study area.

4.7 Historic Building Footprint Reconstruction Methodology

Whilst the street network is the foundation of the analysis of the changing network properties of the urban fabric, the buildings form an essential component of the built environment that also need to be analysed. Similarly to the street network, the historic building map data is only available as a raster image and needs to be extracted in vector line format from the historic maps so that it can be analysed in the GIS software. Doing so can be an especially time consuming process, so methods of semi-automated building footprint vector data extraction were developed. This was achieved using the RXSpotlight Pro software produced by Rasterex Software a.s. This software is capable of extracting very detailed vector line representations from raster imagery (Figure 26). The extracted vector line representations were then fed back into the GIS where they were cleaned so that only built structures were present in the final datasets.

This processes is carried out on two of the case studies, Surbiton and South Norwood that will be subject to the most detailed built environment analysis. The same source maps used for the street network redrawing (OS Country Series 1:2500) were used here, ensuring that the reconstructed built record matches the time period of the reconstructed street network (although it should be pointed out that inevitably there are time lags in the surveying and updating of the maps, especially when a large area is being studied).

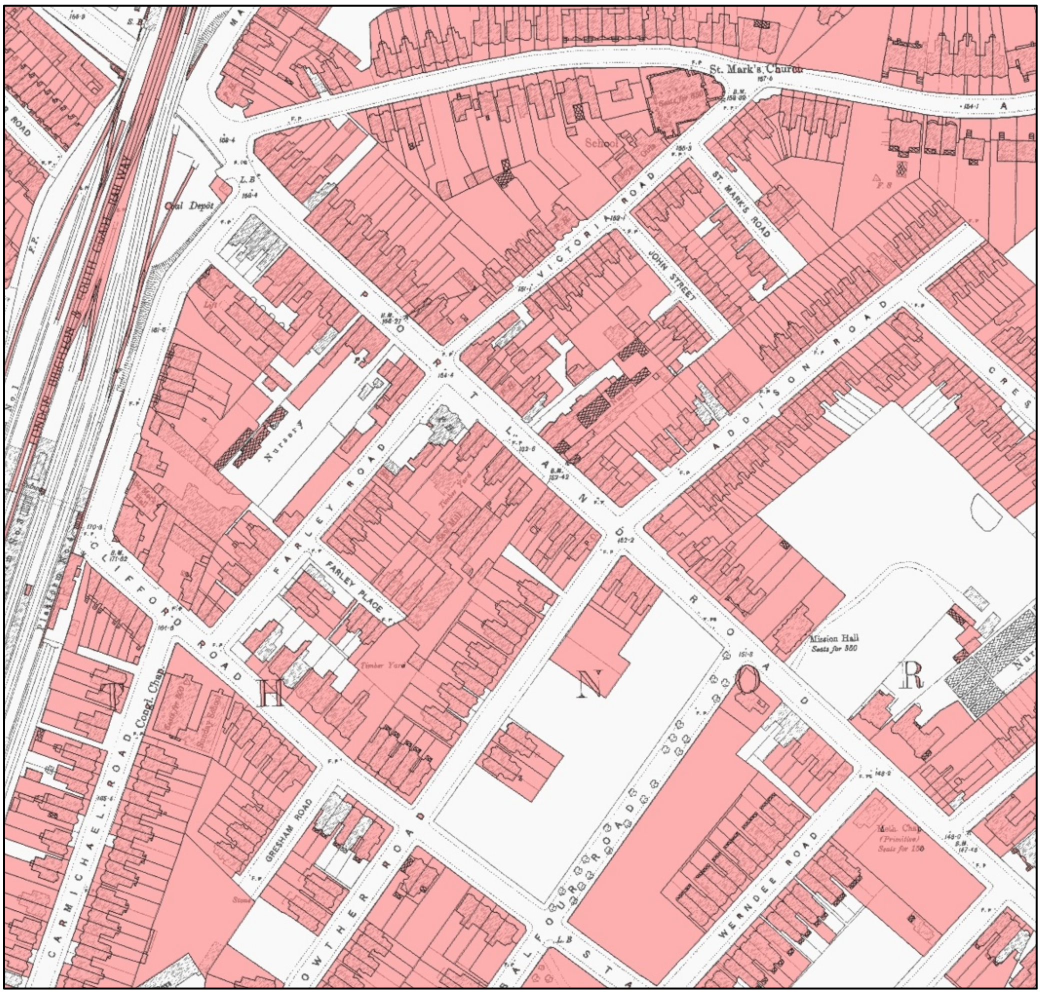


Figure 26 Automated vector extractions from historic mapping using RxSpotlight Pro software (red areas represent automatically extracted polygons).

A rigorous manual cleaning process was necessary prior to the data being used to remove ‘noise’ in the historic maps data such as cartographic symbols and text as well as minor errors in the automated redrawing.

4.8 Avoiding Edge Effect Issues in Analysis of Sub-Sections of Street Networks

In the past, space syntax research using axial lines has required the creation of a boundary of minimum of 2km from the outer edge of a study area to avoid the edge effect – the distortion in values for lines at the edge of a system that was known to occur in radius *n* calculations. It was found that values would not be representative of the reality on the ground because there is no network beyond the artificial boundary that is imposed on the analysis area; typically, streets would seem more segregated than they might be in reality. Recent space syntax analysis using segment choice and integration has assumed that this problem has been overcome to a degree through the normalisation methods for choice values. However, the Adaptable Suburbs research project found that this problem persists, particularly in the more porous networks on the edge of the system such as the cases shown in this thesis; even more is the case with cut-outs of the historic street network. Cut-outs of an area encompassing a radius of 6km ($28km^2$) from the centre of the four case study centres are used due to the extensive time requirements of the cartographic re-drawing process; therefore it was only feasible to reconstruct the historic network for this area around each case study. Using the recently developed method to normalise choice values was found to not compensate for this, as will be shown below.

A generally applicable rule was assumed, stemming from the standard method used in axial mapping (which determines that the average axial step depth from the most globally integrated line determines the maximum radius of analysis before edge effect occurs): the distance away from the centre that can be included in the analysis is the total network distance from centre (TN) minus the metric distance of analysis (MD). See Figure 27, which illustrates that only network segments that *are less than the maximum analysis radius from the edge of the network* can be compared against one another. Here the maximum analysable is the 3km Network Area boundary for analysis of up to 3000m distance.

To test this rule the same network was processed within GIS software and 1km bands around the network were removed iteratively. This yielded four networks with varying network coverage distances from the centre of the network: 6km, 5km, 4km, and 3km. These networks were then analysed within Depthmap and segment values were compared between the four networks. The measures that were compared were choice and integration at metric radii of 800m, 2000m, 3000m and *n*m (whole network). It was found that the values in all four networks remained constant if the radii of analysis never broke the rule described above. If the radii of analysis exceeded the distance of a segment from the edge of the network the value would not be consistent across all four network analyses and the values could not be compared directly as they were subject to edge effects. Whilst this method was examined and developed specifically in relation to historic analysis methods it could also be applied to comparing different areas in different locations or cities.

Further testing showed that for smaller metric radii such as 800m, the distance between the edge of the network and the analysable area is only 800m; for larger radii the gap between the analysable area and the total network area increases – a 5000m analysable area requires a 5000m gap between the edge of the network and the network area being analysed. This is assuming that the network is a simple straight-line network. In reality the network will likely not be linear and therefore maximum analysable areas can be determined through network distance measurements, which will mean a greater metric distance of analysis can be used than the Euclidean distance suggests. This method would require specific measurements for each network being analysed: therefore the general rule described above can be applied to any network, whilst a more specific maximum analysis radius could be developed for each network.

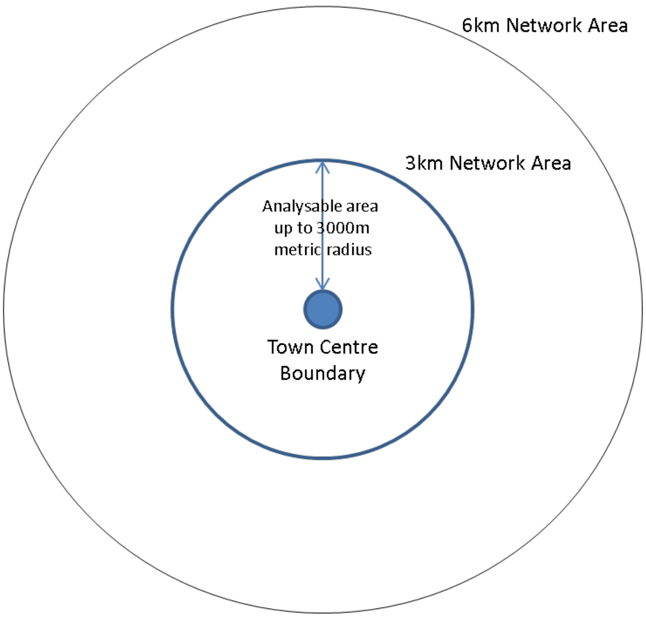


Figure 27 Analysis Area Diagram

4.9 Measuring Distance and Modelling Connectivity in Networks

The analysis buffer is vital for ensuring that the results generated from the network analysis are consistent and not affected by the use of cut-outs of larger network areas. Alongside the effects of artificial edges on network analysis an understanding of the relationship between representations of the street network and the analysis methodologies that are employed are also key. In this research the road centre-line street network representation was chosen based on a comparative analysis of the properties of three different network representations presented earlier in this chapter. On top of these considerations there is the issue of how distance, also called depth, is measured in the network (Porta et al., 2006). Distance can be understood in multiple ways, and space syntax utilises a specific conception of distance in the analysis of street networks, namely angular distance (Hillier, 1996). Angular distance in space syntax analysis is defined as the sum of angular change, this is calculated by summing up the number of degrees that have to be turned to continue moving through the network at each of the junctions between two segments as they accumulate along a route from an origin to a destination. This is broadly called topological distance. For axial analysis (which was the standard method in space syntax until the more recent invention of segment analysis), a simpler form of topological distance is used. Called step-depth, it counts each time a new space that is represented as a separate spatial entity is traversed as a step – in simple terms, it counts the number of turnings taken from each axial line to a neighbouring axial line (Penn, 2003). Unlike angular distance it does not take into account the angular magnitude of the change between network segments. The other principal form of distance that is used in the analysis of street network is metric distance. Metric distance does not consider at all the magnitude, angularity or instances of moving between segments, and simply calculates the distance between origin and destination as the sum of segment lengths along the route, defining length as the metric distance along the lines between the mid-points of two adjacent segments (Hillier and Iida, 2005). Metric distance is not normally used in space syntax analysis.

The other aspect of distance, or depth, that must be considered is the representation of connectivity in the network that is used (Porta et al, 2006). This relates to primal and dual representations of the network. The primal representation of a street network uses the nodes that are the points of intersection between segments as the units of analysis, and examines how they connect to one another through the street segments, which are the edges in the network, using Euclidean or another conception of distance. The dual representation is derived from the primal, and represents the connectivity that exists between the edges, or segments within the street network. In the dual representation of connectivity the edges of the network become the nodes and the intersections are the edges (Batty, 2004). This produces a different model of connectivity that represents the edge-to-edge connectivity between street segments in the network, this is the approach that is used in the space syntax methodology (Hillier, 1996; Hillier and Hanson, 1984). Using this representation of network connectivity, the unit of analysis is transferred from the intersections in the network to the segments themselves, allowing the analysis to examine the relationships between spaces, rather than the points of intersection between spaces. To be able to take into account metric length within the space syntax approach to network representation and analysis, Turner (2007) proposed the weighting of values by segment length, when using road centre-line network models. This was shown to improve the predictive power of the model when examined in relation to pedestrian flow data. It can be seen that the analysis of street networks is not straightforward and the spatial relationships across the network can be understood in multiple ways, in both how distance is conceived and how the connectivity of the network is modelled in the primal and dual approaches. In this research the road centre-line street network representation that is used is converted to the dual representation of connectivity, which is then weighted by segment length. Through this weighting process the primal and dual issue is somewhat overcome by taking into account the length of individual segments in the calculation of the centrality values on the dual representation of the street network.

4.10 Limitations

Whilst the approaches to the data used in this research have been shown to be rigorous and expansive in their spatial extent and detail there are still some limitations to the approach that have to be borne in mind. The primary limitation is that the historical street network and built form record reconstruction does not encompass the whole of London. The street network is reconstructed for the 28km^2 circular area around each of the four case study areas. This limitation arises from the large time cost of the cartographic re-drawing process precluding the possibility of reconstructing the entire London street network for the three historical periods. Although this limits spatial extent of the network analysis to a smaller area, the analysis will still be able to account for the local development of the street network and any developments in the area that come about due to city-wide processes. Furthermore the aim of this research is to account for local changes in the urban fabric and analysis of the whole city region would not facilitate this further than analysis of the smaller areas. The built form record is limited to two case study areas, again due to time cost constraints. Whilst this process has been semi-automated through the methodological developments outlined above, it still very labour intensive during the cleaning stage of the process, especially considering the high density of buildings in some of the case study areas and the quality of the mapping that is available. The other limitation is that the street network reconstruction and contemporary model only contain elements classified as streets or roads, other pathways are not present in the network model. This is due to the ambiguity that is found in historical map records leading to a situation where determining whether a path exists or not becomes highly complicated and subjective. This is also the case in the contemporary data where pathways are only classified if they are public rights of way, therefore excluding those that might be important pedestrian routes but are privately owned or not accessible at all times. In order to avoid this subjectivity the criteria of being a street or road was used since this category is far less subjective and uniformly marked in historic mapping, ensuring historical continuity of the street network representation, and thus analytical outputs.

4.11 Summary

Using the outlined data and methodological approaches to creating the data for analysis in this thesis the following questions are going to be addressed:

‘What are the morphological centrality and built form characteristics of peri-urban London as it has developed over the period 1880-2013?’

‘How can GIS and Space Syntax research methodologies be combined and enhanced to enable efficient and detailed, large-scale analyses?’

With the first question containing two subcomponents:

1. What have been the patterns in the development of peri-urban London’s street network in the period 1880-2013 and are there coherent structural patterns to this development?

2. How have the built forms that populate the street network developed over this period, and are there specific forms associated with peri-urban areas?

These questions are addressed through a space syntax network analysis of the street network and built form record at four time intervals over 130 years in four suburban case study areas. The analysis outputs will then be used to compare between the four suburban case studies and analyse how the street network and built form have co-evolved over 150 years to create areas that are now referred to as suburban in character. This analysis will enable an understanding of the architectural and spatial characteristics of these areas.

This research questions aims to develop an understanding of the city-creation process from the perspective of both the small local-scale, and the regional scale by carrying out both local and sub-regional analyses. This is achieved by looking at four suburban areas on the fringes of London that historically were not part of the contiguous urban area of London, that over the last 130 years have become embedded within the physical and conceptual space of London. The suburban areas are be analysed in detail at their local scale but then they will also be examined in contrast and relation to a larger area that they are situated within, taking into account the adjacent settlements. This will provide the means to develop an analysis that is mindful of the trans-scalar social and physical relationships that exist in the cities. It will also mesh the spatial historical narratives of the local and regional, enabling insight that is often lost through focussing on one particular spatial scale or using analysis tools that may not be suitable for the analysis of different spatial scales.

The second research question relating to research methods uses as a starting point the work of Turner (2007) who looked at the feasibility of using road centre line network representations in space syntax analysis as an alternative to axial representations. Multiple data sources were evaluated to understand the morphological differences in representation that is embedded within them. The question of integrating techniques is also approached through the methods used in constructing chronologies of built form and bringing together analysis approaches to create a richer understanding of the spatial and physical evolution of peri-urban London.

In the discussion and analysis of the different models of urban environments currently available it is clear that work has to be done to reconcile the underlying network representation with the analytical toolkit of space syntax. Whilst it is possible to create and analyse models that are accepted and easy to justify on theoretical grounds, it is necessary to revisit the fundamental building blocks for the practical analysis of urban environments, especially as computing power and research directions nowadays lead to increasingly large areas, and complex interrelated variables to be studied. Two key factors that drive this are; the widespread adoption in space syntax research of angular segment analysis techniques, that might be better served by detailed road centre-line accounts of the geometric relationships between line segments, and the need to analyse the city network and the surrounding urban environment as one system. This would also be more readily facilitated by road centre-line representations that are spatially congruent with the urban built form.

How the real world is represented through data is a vital area that cannot be overlooked. The axial line laid the foundations for the discipline of space syntax and serves a very powerful purpose in how it represents the linkages between space in the city, but if the axial line can be substituted as a representation for a more widely understood model that brings with it a greater detail to the analysis, and that can be analysed with space syntax tools– arguably this might be the preferred method in the future. This chapter has demonstrated that a model based on road centrelines – so long as its traffic management detail is simplified - has the potential to provide a robust and replicable model that both: captures spatial configuration for individuals as they use and understand their local environment; as well as reflects the configuration of the local environment within the context of an entire city.

The cartographic-redrawing method employed for the reconstruction of the street network that have been presented, combine the utilisation of the ITN road-centre line network representation with historical data to enable accurate reconstruction of past urban street network. Through the combination of this data source and the historical mapping, accuracy and speed in the reconstruction of the street network is possible, as well as consistency across all four case studies that are going to be reconstructed and analysed. By applying novel software techniques, the extraction of the building footprint records can be far more easily accomplished, enabling the research to look is detail at the evolution of built form across two of the case studies (the rationale for choosing the two is outlined in chapter 7). The combination of detailed and consistent street network records, and built form records allow highly detailed and nuanced analyses of the evolution of suburban built form through time.

The final methods section presented the approach to analysing sub-sections of urban street networks. This approach allows for sub-sections to be analysed without the effects of the absence of large parts of the street network to impact on the results. By combining these evaluation and analytical approaches, the methods that are employed in space syntax research can be improved and become consistent with other areas of urban spatial research, so that the cross-disciplinary dialogue can be facilitated more easily, without the barriers of data approaches and methods that have existed for so long.

5 Whole London Contextual Analysis

5.1 Introduction

This chapter presents an analysis of the basic network properties and space syntax of the whole London network model that was selected for the starting point of the historical reconstruction of the four case study areas. An introductory analysis is presented of London as a whole in 2013, through basic network descriptions, proceeded by a comparative space syntax analysis of the four case study centres in relation to four centrally located sub-centres. The comparative analysis looks at the differing network centrality of the centres across scales, in order to characterise the differences in the network properties between centrally located and peripheral centres within the London street network. Understanding the relative network properties of central and peripheral locations is vital in understanding how they function spatially and socially within the context of London as a whole; this is particularly important when considering different scales, as centres function across scales both in relation to pure spatial measures but also more intangible social and cultural factors.

In the previous chapter the analysis of axial, Open Street Map and the Ordnance Survey's Integrated Transport Network (ITN) street network representations' suitability for space syntax analysis was presented. It was found that although they are philosophically, geometrically and procedurally very different, they represent the network of the city in very similar ways, the only principal difference being the resolution and variance in the centrality measures that were generated. The highly detailed ITN representation produced the greatest range of values and the most variance in connectivity. These qualities along with the standard practices in the dataset production and the interoperability with other standard UK mapping datasets made it the most desirable from the perspective of both highly detailed analytical results and the data integration standpoint. Furthermore the standardisation makes the process of cartographic re-drawing for historical analyses simpler and more reliable. Although it has these desirable qualities it required more processing in order to make it compatible with space syntax analysis and also far greater processing times than an axial street network model.

Due to the highly detailed nature of the ITN road centre-line network representation the London-wide network model is highly complex; the model contains approximately 1.2 million individual network elements. In order to make the network suitable for the specific requirements of space syntax analysis and the Depthmap software (Turner, 2007) that is used in space syntax analysis, significant processing was required. Polylines, single network elements that are made up of multiple sub elements that do not share the same geometry, cannot be processed, so the network has to be split into individual geometric elements. Furthermore processing was carried out in order to remove traffic control features, such as traffic islands, that break continuous road segments that do not have any change in their angular orientation. Significant processing was also required to preserve the overpasses and underpasses as separated network elements so that the analysis was representative of the actual connectivity in the network rather than a simplified planar graph representation. For the highest radius of analysis of 10,000 metres the computation time was approximately 350 hours. In order to complete this single network centrality measure approximately 1.4×10^{12} calculations were performed.

A limitation that is encountered when dealing with such a large network, is that the edge effects (described in the previous chapter), cannot be fully compensated for when carrying out analysis at this scale because the buffer area would have to be so large that computationally it would be extremely costly, therefore for the intentions of this analysis the network is considered to be representative of an entire system, especially due to the lower density of network elements outside the 3km buffer around the M25, as used in these analyses. With this in mind the space syntax integration analysis must be viewed with the impact of edge effects taken into consideration.

5.2 Case studies' street network overview

In figure 1 the London-wide network that was created for subsequent analyses is shown. This network covers 2932 km^2 and contains a total of 26,011km of street network. The boundary that was chosen for the London wide analysis, as shown in blue, is larger than the official boundaries of inner and outer London as defined in the 2011 London Plan created by the Greater London Authority (figure 4). The reason for using an enlarged area for the street network model is two fold; firstly three of the four peripheral case studies fall partially outside the largest official boundary of London, and secondly in network terms the M25 orbital motorway (shown in red in figure 2) is the most clearly defined continuous boundary, this boundary was then extended by 3km to capture the network that is adjacent to, but outside this network structure; accounting for the fact that there are no clear boundaries that are easily defined, especially when evaluating a largely continuous structure such as a road network.

Figure 1 London wide street network dataset, case studies and 3km analysis boundaries shown

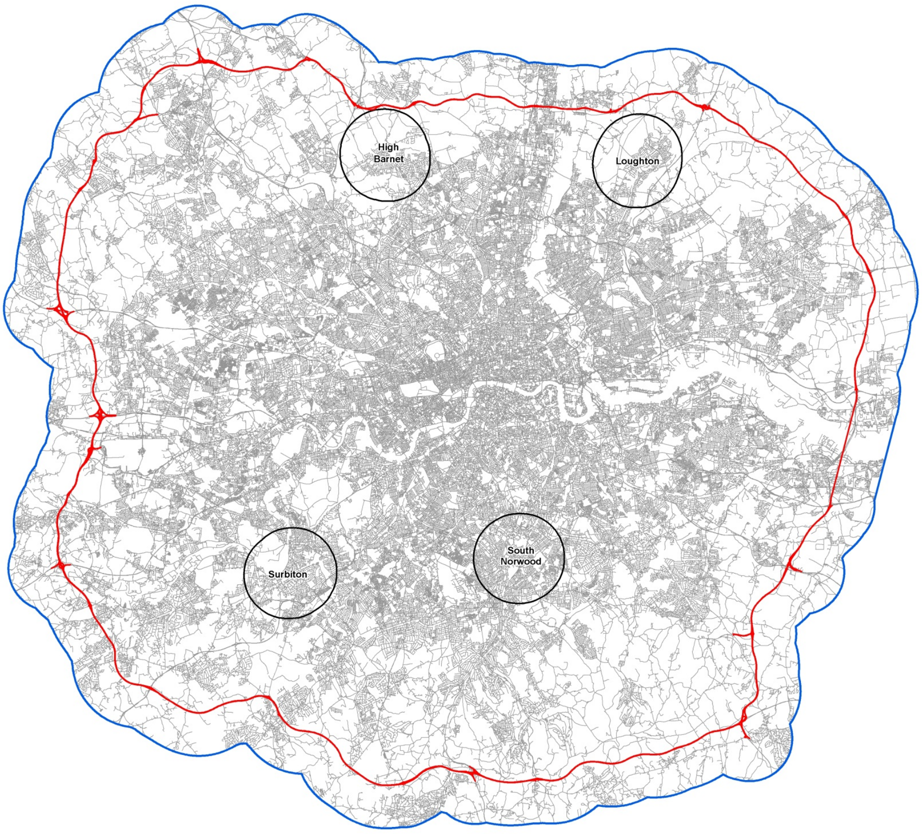


Figure 2 London wide street network dataset with M25 ring-road overlaid highlighted in red

Figure 1 also shows the four case study areas of High Barnet, Loughton, Surbiton and South Norwood. These are the four case studies that are to be reconstructed and analysed to chart their morphological development through time. In figure 2 and 3 the reconstructed networks for the four periods of analysis for High Barnet and Loughton; and Surbiton and South Norwood respectively are shown. In these images the full 6km radius of network reconstruction is shown. In all further analysis only the central 3km radius from the town centre boundary is used. This approach is the result of the method that was developed to avoid edge effects when analysing cut outs of continuous networks, as outlined in the previous chapter. In table 1 the size in square kilometres is given for each of the case study areas' six and three kilometre study areas. The difference in size is due to the differing size of the town centre boundaries that define the central core of high street functions, this alters the size of the study area when buffered by a fixed distance.

Initial observation of the network in figures 3 and 4 of development over the 130-year period shows that there has been dramatic development of the network across all the four case studies. In Surbiton and South Norwood there has been a more even and continuous growth of the network in comparison to Loughton and High Barnet where the network is still very fragmented and does not fill the space entirely with large areas remaining un-filled. Their locations within the London network may also relate to this difference, as South Norwood is closer to the centre of the urban area (figures 1 and 2) and will therefore be more likely to be urbanised in an earlier period as the city and its environs grew.

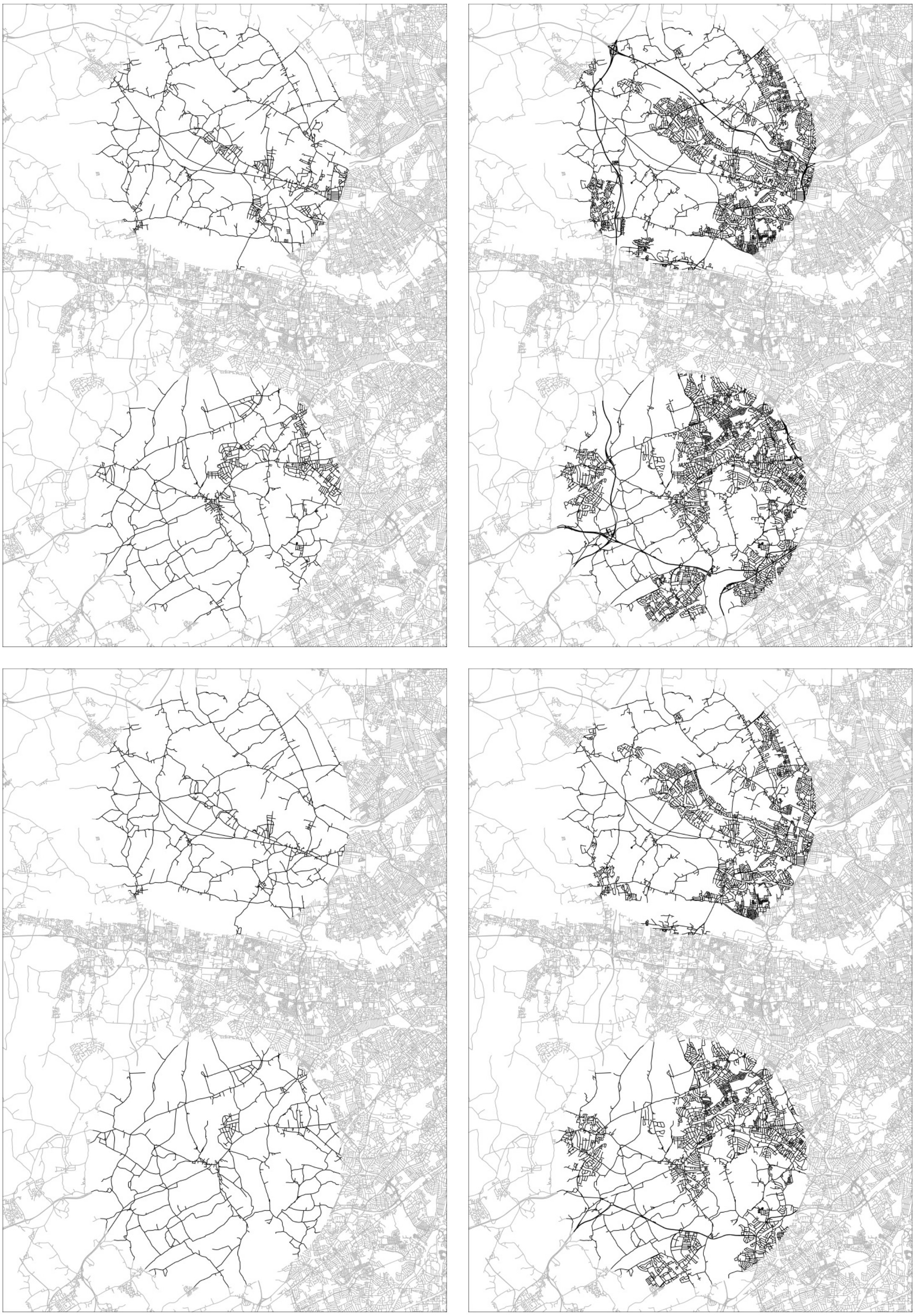


Figure 3 Reconstructed 6km boundary street networks; High Barnet left and Loughton right in black, set against contemporary street network in grey

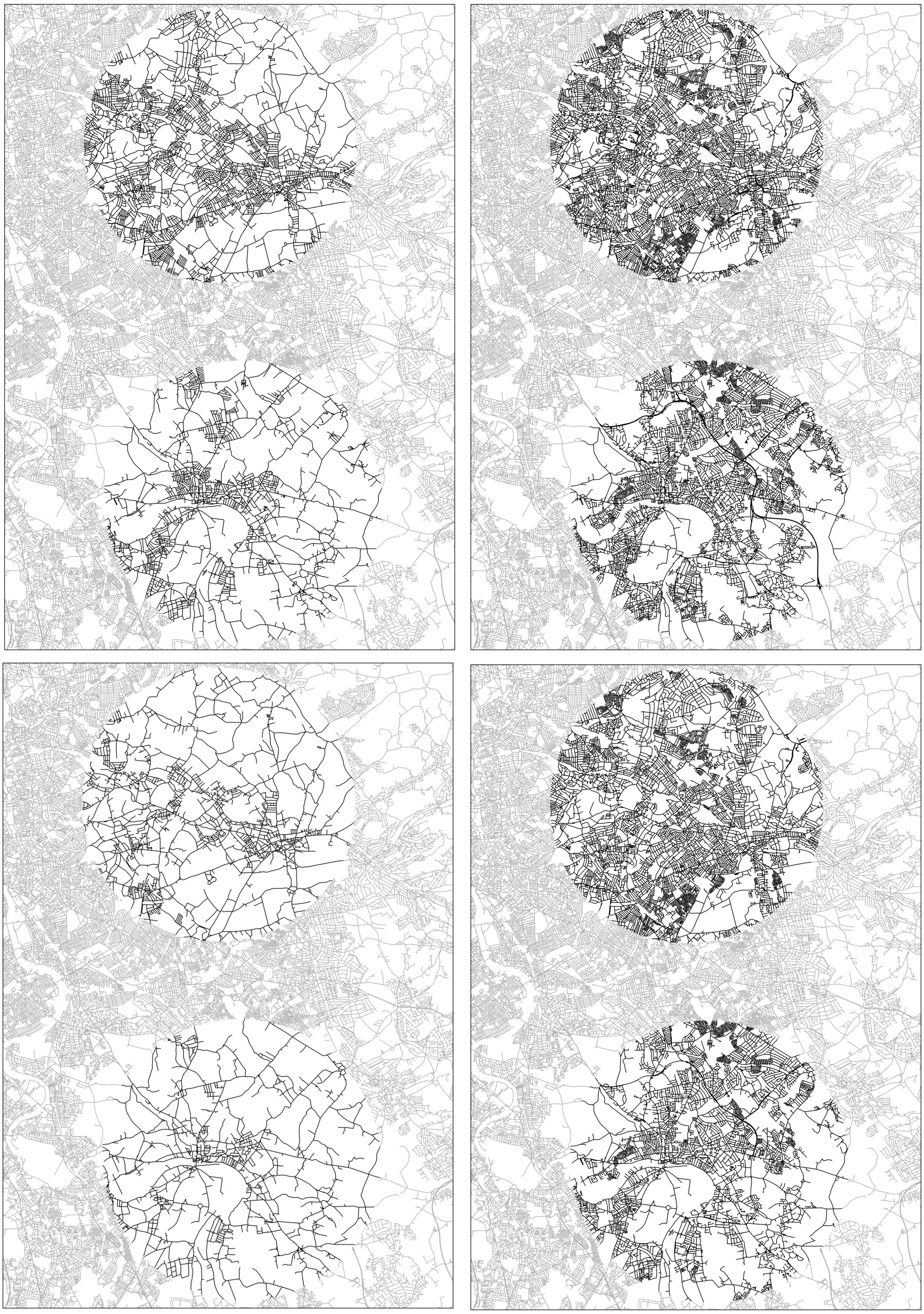


Figure 4 Reconstructed 6km boundary street networks; Surbiton left and South Norwood right in black, set against contemporary street network in grey

	3km Analysis Area	6km Reconstruction Area
High Barnet	34.36	124.96
Loughton	34.46	125.21
Surbiton	34.45	125.15
South Norwood	31.66	119.74

Table 1 Size of 3km analysis and 6km reconstruction areas for each case study

There are also other factors that limit even growth, such as protected areas, as in the case of Epping Forest to the north-west of the Loughton study area, and Hampton Court Palace and Gardens to the north-west of Surbiton study area (figure 5).

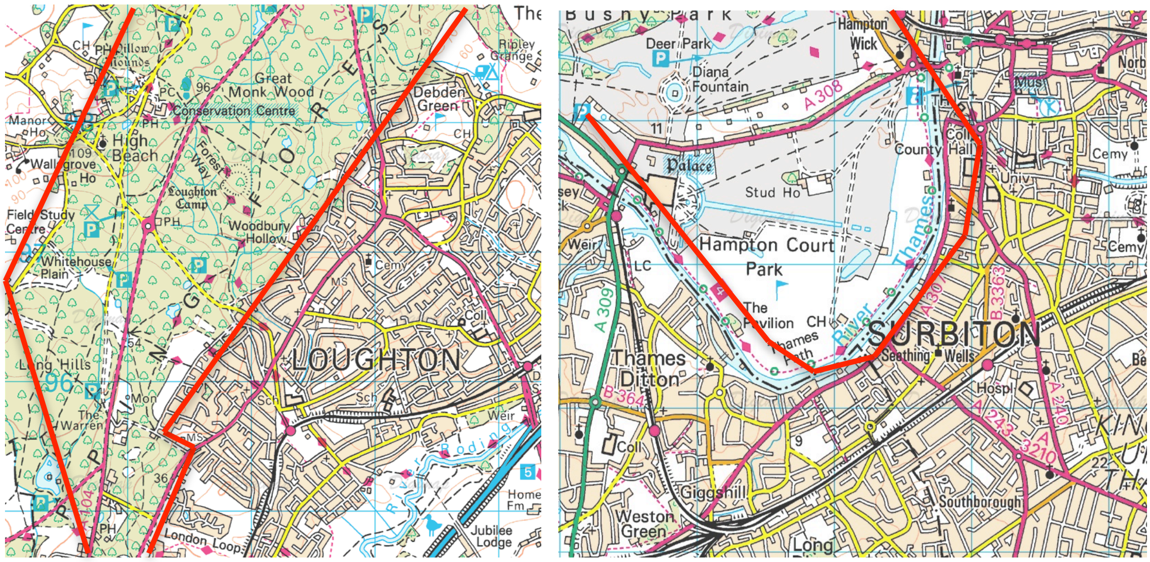
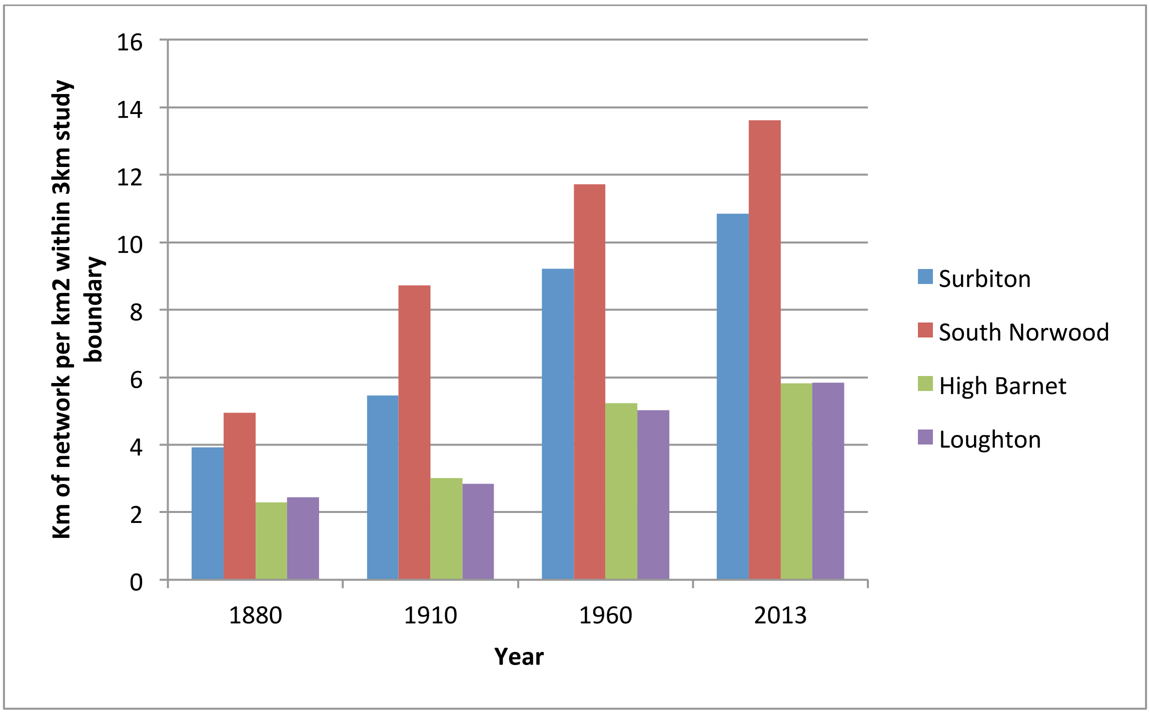


Figure 5 Maps showing constraints to growth; Epping Forest adjacent to Loughton (left) and Hampton Court Palace and Park adjacent to Surbiton (right). Contains Ordnance Survey data © Crown copyright and database right 2014

In graph 1 the development of the network is shown for each of the four case studies' three-kilometre analysis areas. The values presented in the chart show the density of network in kilometres of network per square kilometre of land area in 2013, these figures are normalised for the differing areas, so that the figures are directly comparable (see table 1). From this it is clear that the initial visual observation of the development of greater network density in Surbiton and South Norwood is correct, with South Norwood having a density of 13.6km/km^2 compared to Loughton with a density of 5.8km/km^2. Strikingly, the density of the network in Loughton in 2013 is comparable in terms of density to that of Surbiton in 1910 with 5.8km/km^2 and 5.4 km/km^2 respectively. There is also a clear linear progression through time as the network develops in all four cases. The chart also illustrates how constant the proportional relationships are between the case studies, in 2013 High Barnet is approximately half the density of Surbiton and this was also the case in 1880. In fact, all the case studies retain roughly constantly proportional relationships. This suggests that even the development that we see in the contemporary city has its roots in the initial structure and topology of development that began centuries ago. This confirms the necessity of an appreciation for the historical processes in understanding both the present and future planning for these.



Graph 1 Street network density (km/km^2) from 1880 to 2013 in each case study

5.3 Network properties: density, junction and dead ends

5.3.1 Network density

Whilst this introductory analysis of the network and its development in the four case studies captures the basic network development of the four case studies, it is necessary to contextualise this development in relation to the network characteristics of London as a whole, and extend the analysis beyond network density alone. In order to do this it is helpful to divide the network of London into four categories for comparison with the historical development of the network in the case study areas. In figure 6 the divisions of the London network that are used are shown. Two of the boundaries are official boundaries; Inner and Outer London, as defined by the 2011 London Plan produced by the Mayor’s Office at the Greater London Authority, and two which have been created in order to expand the area of network considered as London to encompass the M25 and three kilometres beyond, as described earlier. The two extra divisions of the network are the entirety of the network extending three kilometres beyond the M25, and the portion of the network that is between the boundary of Outer London and three-kilometre M25 boundary, termed M25 Outer. Through these divisions of the network 20 different values for the network properties are generated: four for each case study for the four historical time periods of analysis and one for each of the spatial divisions of the whole London network. In table two the total network length in each of these subdivisions is given as well as the corresponding area.

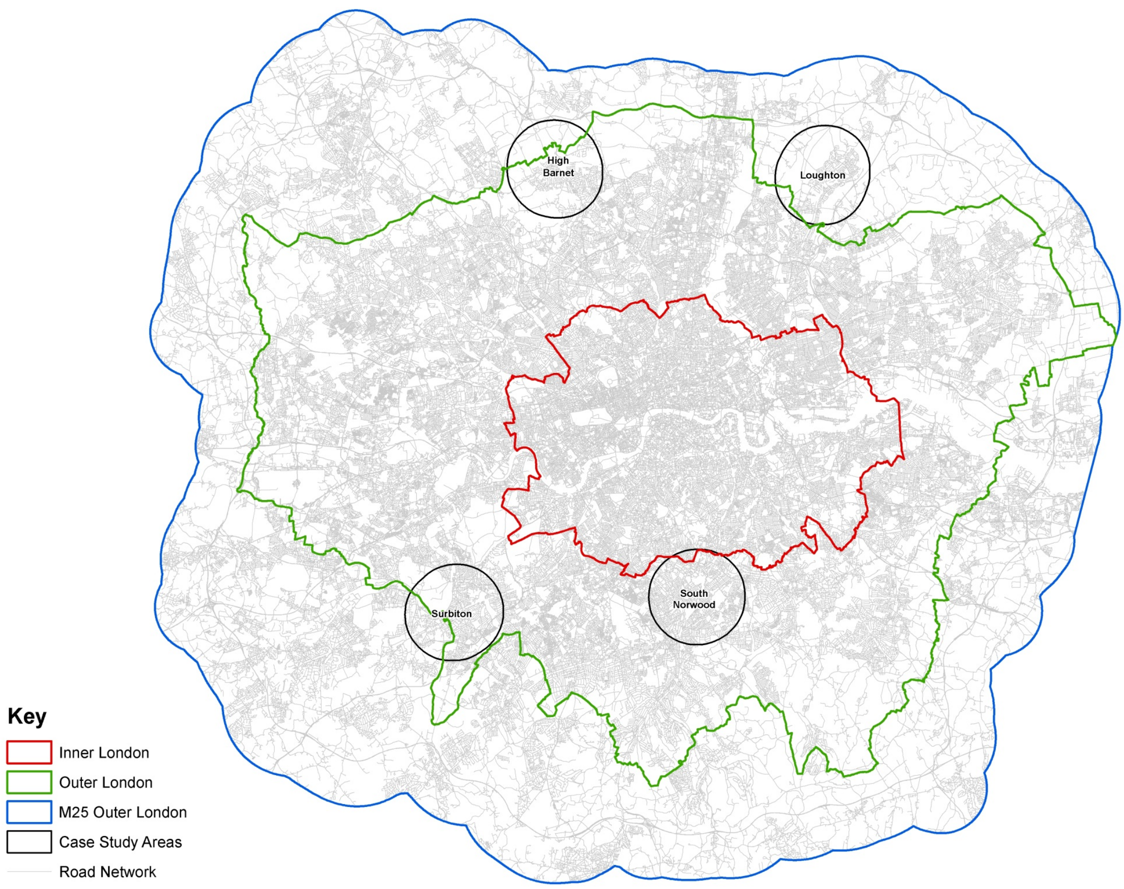
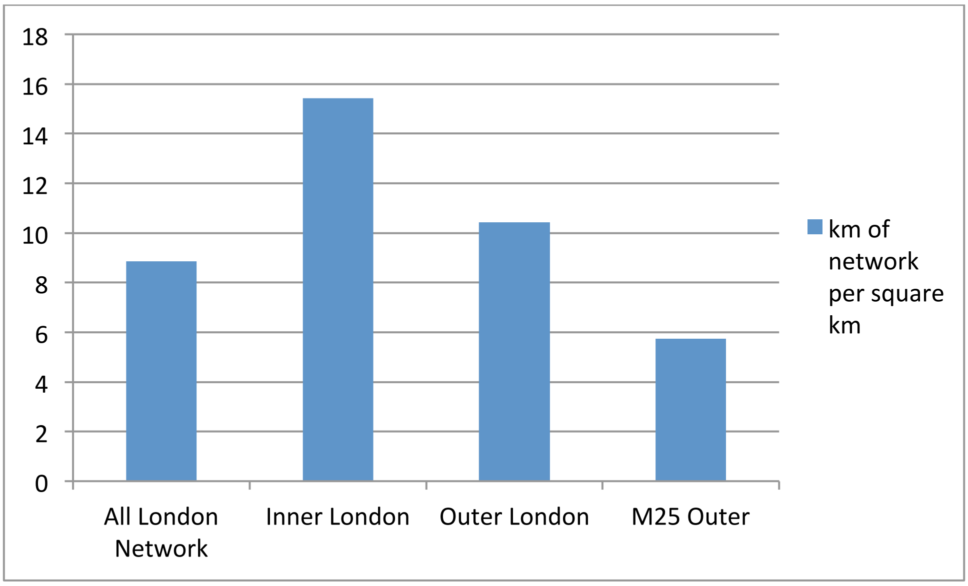


Figure 6 Map showing analysis subdivisions of London street network

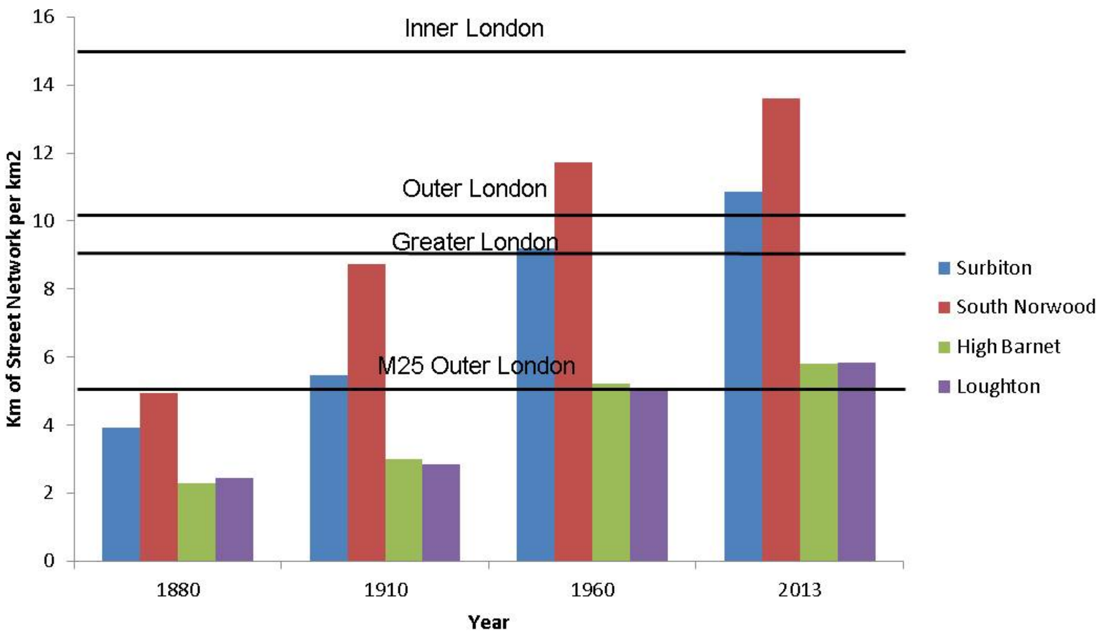
	Length of network (km)	Area (km2)	Density (km/km2)
All London Network	26011.3	2932.24	8.87
Inner London	5382.48	348.63	15.44
Outer London	12982.27	1246.07	10.42
M25 Outer	7685.66	1337.76	5.75

Table 2 Network length and subdivision area for whole London street network

In graph 2 the network density values for each of the London network division are presented. The 'All London Network' can be considered as an average value for the whole network. As would be expected the density of the network in the Inner London region is the highest with a value of 15.4 km/km^2 and then Outer London is second lowest whilst the M25 Outer area is the lowest. When this is considered in relation to the four case studies and their historical development in graph 3, their developmental trajectory shows a trend of increasing density to levels that are in-line with their spatial positioning within the subdivisions of London, with the exception of High Barnet (see figure 4). South Norwood sits largely just outside the Inner London area and has a density value of 13.6 km/km^2 that is just below the Inner London average density. Surbiton, which straddles the Outer London and M25 Outer boundaries, has a value just above the Outer London average whilst Loughton and High Barnet have very similar density levels that are just above the M25 Outer average. High Barnet stands out in this comparison due to its density being significantly lower than the Outer London average but being within similar range of values as Surbiton. In terms of the Outer London boundary as defined by The London Plan, it is clear that whilst Surbiton and High Barnet share similar spatial positioning in relation to it, they have very different network densities. This alludes to the greatly varying network structures that exist amongst town centres within similar geo-political regions. It also raises the question whether the properties of the network will show defined differences in the spatial structure when investigated further.



Graph 2 Network density for London street network subdivisions



Graph 3 historical network density changes in case studies in comparison to contemporary London network subdivisions

5.3.2 Junctions and dead ends

The analysis of the changing density of the street network across the four case studies in relation to the whole of London as it is today, allows an understanding of the extent to which the network has grown over time, but it fails to capture the nature of the connectivity aspect of the network. In order to understand the structure of the street network it is useful to consider the density of junction points in the network (Masucci et al., 2013) and also the relationship between junctions and dead ends. By measuring the junction density an approximation for the density of street network connectivity can be generated, and by examining the ratio between junctions and dead-ends in the network, the connectivity in relation to exploratory network growth can be examined. The following time series analysis of the four case studies will therefore allow for a characterisation of the type of growth that occurs in each period.

In figure 7 an example of a network with the junctions (green) and dead-ends (red) is shown to illustrate the characteristics of each type of node, connective (junctions) versus exploratory (dead-ends). The connective nodes are that which form the junctions between different sections of the network, linking together the network elements that span the space, integrating them together. Dead-ends are the terminus points of the network from which no further space can be accessed through the network. These can be considered as exploratory network elements since they are the furthest point that the network can, or has reached, along the route through the network that they represent the final point of.

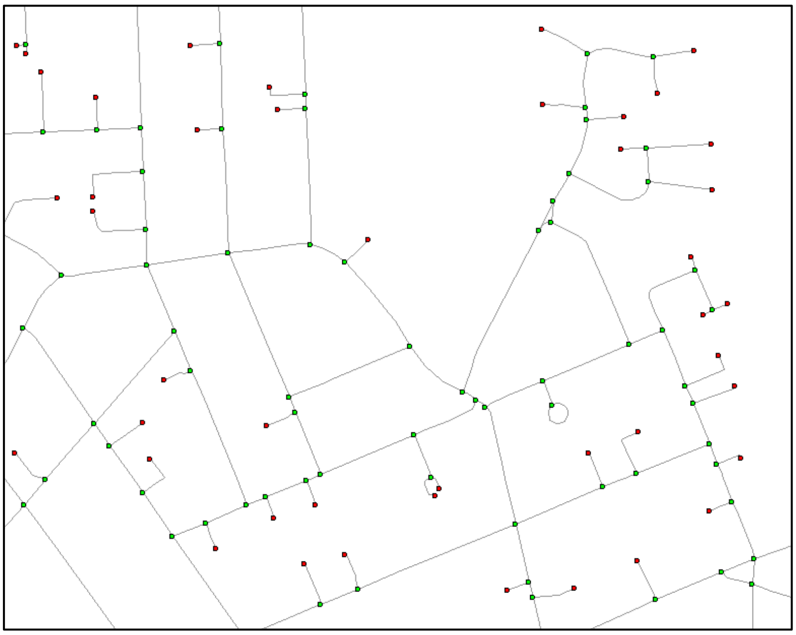


Figure 7 Map showing junctions in comparison to dead ends

In figure 8 the map shows a surface that represents the density of junction points across the whole network. This was created using the Kriging method of density estimation within the GIS software. This method creates a continuous surface of values across a defined area through the estimation of probable values for densities in specific locations based on the location a known variable that the density estimation is based on. In this case those known values are the locations of junctions. It can be seen that generally the highest density of junctions is in the centre of the city and on radial routes out of the centre, as would be expected. In addition to this primary structure of junction density there is a patchwork of disconnected areas of high junction density reflecting the polycentric nature of London. One outlier in the pattern of junction density is the area to the west of the centre with a very high density of junctions; the corresponding area of the network is shown in figure 9, this area is a planned housing estate with numerous back streets for access to garages creating many junction points over a very small area as shown in figure 9.

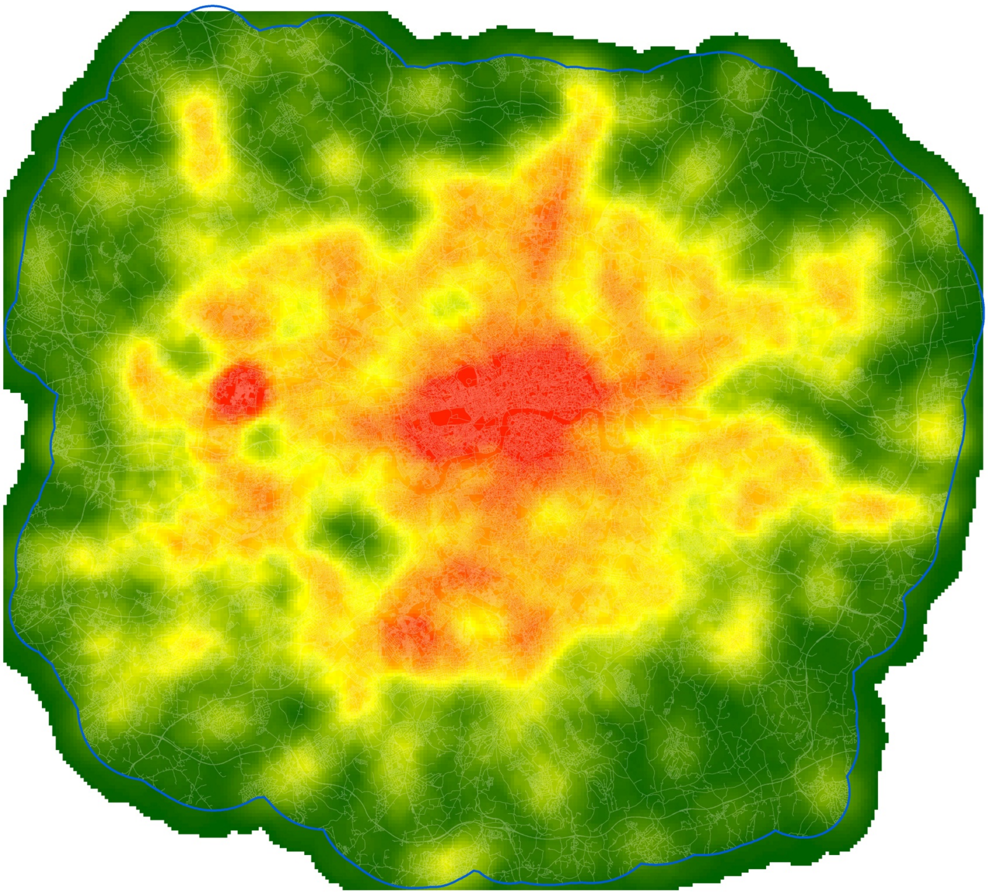
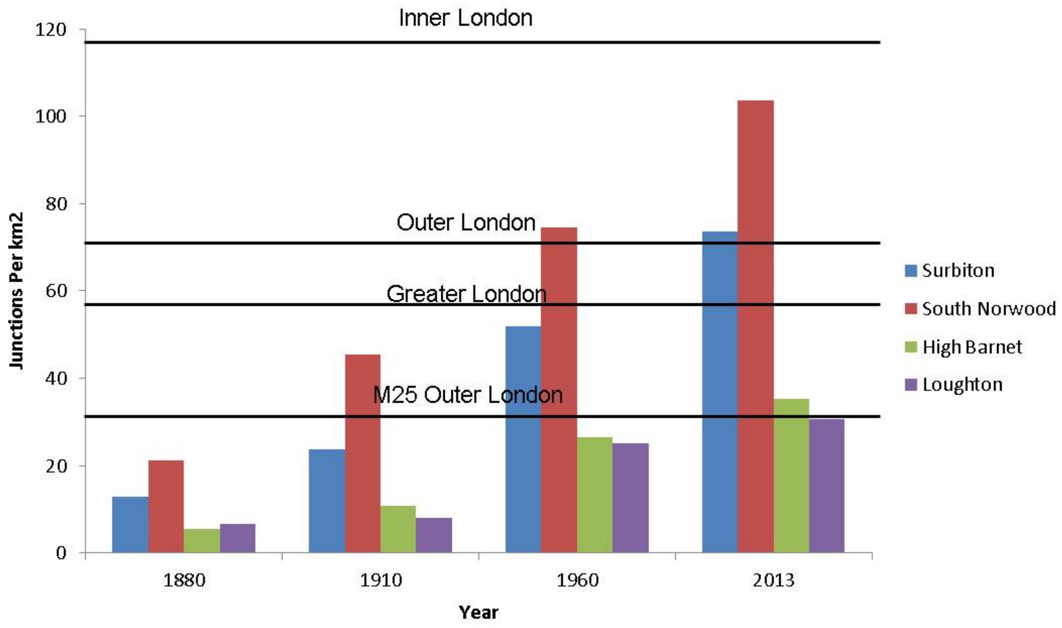


Figure 8 Map showing density surface of junctions across London street network area

Figure 9 Map highlighting network of high-density junction points

In graph 4 the four case studies' junction density through time are shown in relation to London in 2013 divided by the boundaries described earlier and shown in figure 4. A similar trend to that observed in graph 3 is present here, with a linear progression of the development of junction density over time across the four case studies with Surbiton and South Norwood having the greatest density and High Barnet and

Loughton having significantly lower densities. Again, all cases maintain roughly proportional densities over time as shown in table 3. The areas also conform to their positioning in relation to the divisions of the areas of the whole of London.



Graph 4 Comparison of junction density change in four case study areas in comparison to contemporary London network subdivisions

Junction Density	1880	1910	1960	2013
Surbiton	12.92	23.80	51.99	73.53
South Norwood	21.13	45.51	74.60	103.72
High Barnet	5.41	10.65	26.52	35.25
Loughton	6.53	7.98	25.01	30.73

Table 3 Junction density change through time in case study areas

As mentioned earlier, comparing the ratio of junctions to dead ends within a specific area is useful to understand both the contemporary situation of connectivity, and also the growth process over time, specifically whether it is exploratory or connective growth occurring. In figure 10 the surface shown in figure 8 has been normalised by the density of dead ends. This radically transforms the connectivity image of London from figure 8. The area of extreme junction density in the west is no longer significant as there are many dead ends that negate the number of junctions. The central area of connectivity has also shifted west due to the presence of many dead-ends in East London. The area of very high junction to dead-end ratio density north east of the centre is Ilford, Gants Hill and Redbridge, where the confluence of major highly engineered road networks and dense highly connected local grids creates an area with a high junction to dead-end ratio (figure 11). Another significant location on the map is the dark red patch in the west that is Heathrow Airport; in figure 6 this is an area of low junction density due to the sparse network around the airport, but when the dead ends are considered in the analysis it is shown to be a highly connected portion of the network. This is indicative of its function as a location of purely managing flows to and from the area, so dead ends are not a desirable or necessary quality in the network.

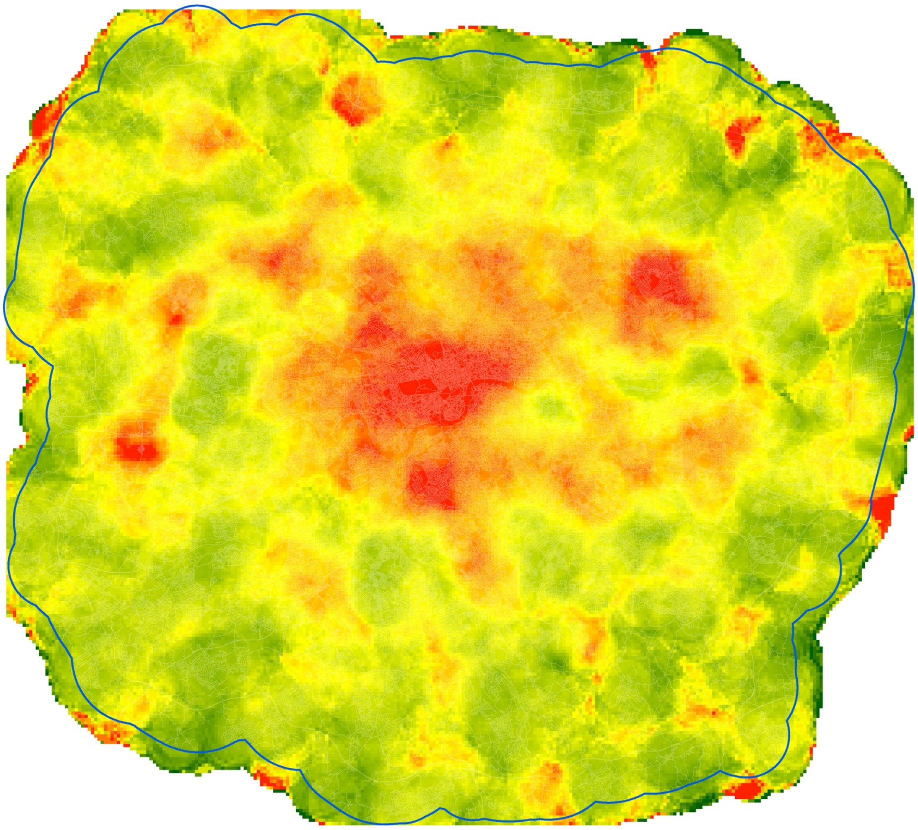
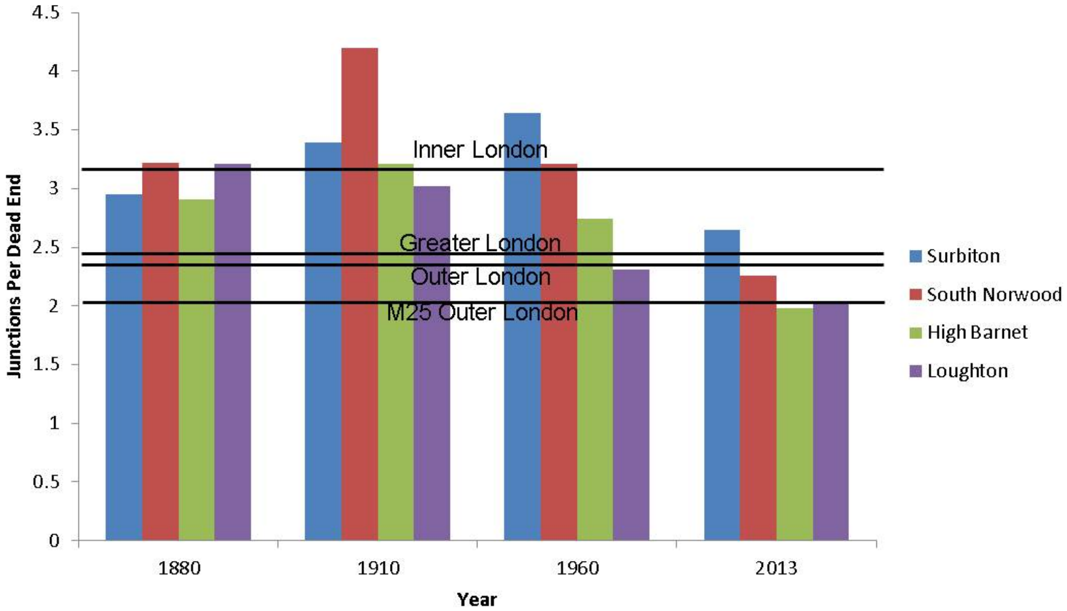


Figure 10 Map showing density surface of ratio of junction to dead ends across London street network area

Figure 11 Gants Hill and Redbridge local network structures

Turning back to the case studies in question, when they are evaluated in terms of their junction to dead end ratios, as shown in graph 5, the trend that has been observed thus far in the network density and junction density analysis does not continue here. Rather than a steady increase, an overall decline can be seen. In understanding the presence of dead-ends as being indicative of exploratory growth in the network, the trend of first an increasing junction to dead-end ratio between 1880 and 1910 and then this declining for subsequent periods, can be understood to show an early stage of connective development consolidating the area and developing a more connected local grid. In the case studies the levels of junction to dead ends reach, and in the case of Surbiton and South Norwood exceed, that of central London today. From 1910 onwards there is a decline in all cases with the exception of Surbiton, as the development pattern of the network changes. This can be attributed to the case study areas becoming focuses for the development of commuter areas of the city, and exploratory growth in the network occurs to provide more space for residential developments. This is primarily achieved through the splitting of land parcels as network elements branch off pre-existing network structures. This is illustrated in figure 12, which shows a portion of the 1960 South Norwood network overlaid on the 1910 map.

It is also interesting to note that although South Norwood has the highest network density and junction density, once dead ends are taken into consideration Surbiton has the most connective network out of the four case studies. This indicates that whilst connectivity as measured by junction density is important, a consideration of disconnection must also be present to understand the overall character of the network and its development trajectory. Space syntax analysis can be used in this regards to explore the overall structure of the network taking into account both connection and disconnection. To further the preliminary investigation of the four case studies' networks the next section presents a space syntax based analysis of the whole London network and then the case studies in comparison to four centrally located sub-centres.



Graph 5 Comparison of junction to dead-end ratio change in case studies in comparison to contemporary London network subdivisions

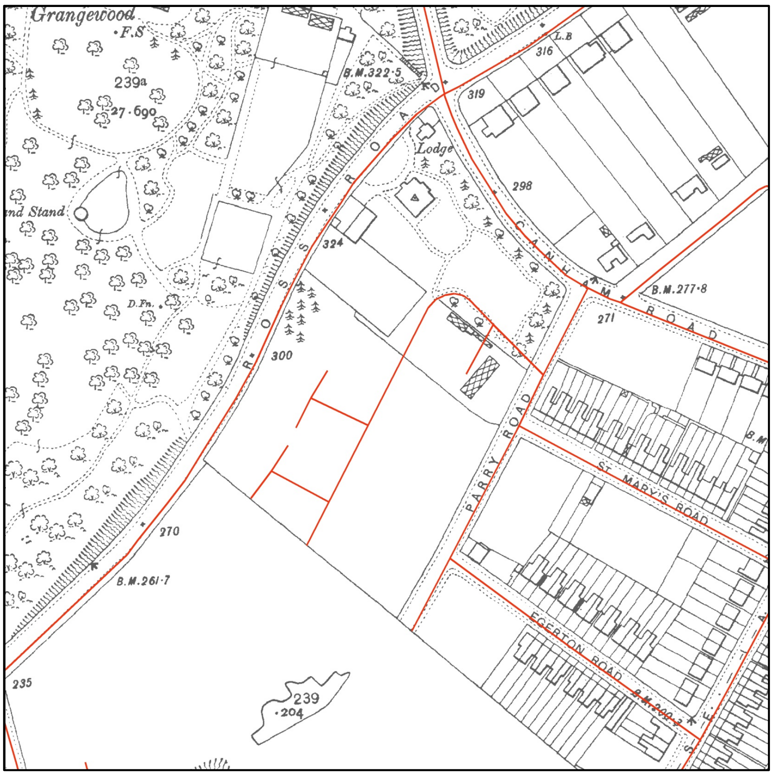


Figure 12 Map showing the development of dead-ends during network growth and parcel subdivision in South Norwood. 1960 network (red) overlaid on 1910 base map.

5.4 London-wide Space Syntax Analysis

5.4.1 Angular Closeness Centrality

In advance of introducing the space syntax analysis of the case study town centres and the comparative centrally located centres, an overview of the space syntax (*syntactic*) structure of the city is presented. Firstly the angular closeness centrality, referred to as *integration* in the field of space syntax is presented. In figures 10 to 14 maps of integration for the London network can be seen. These are ordered in sequential radii of analysis; 800m, 1600m, 3000m, 5000m and 10,000m. The measure of integration reflects the angular change between one edge within the network to all other edges within the specified metric network distance. This measure models movement to locations in the network, due to their positioning on the geometrically simplest and therefore most accessible location in terms of how people navigate space (Hillier, 2009).

In figure 10 clearly defined and scattered peaks in the values of integration can be seen across the network of London. This indicates that there are multiple centres working at the scale of 800m that form distinct locations of high integration. Whilst the centre of London still forms a homogenous area of high integration, areas right up to the edges of the network show strongly defined separate centres of integration. It is also important to note that sections of the London orbital motorway, the M25 are also prominent as having high integration at this scale of analysis. This is a function of both how the analysis approach treats the network and also the physical infrastructural design of the M25. Space syntax analysis treats every segment of the network as a possible origin or destination that is analysed. If the segment is further than 800m from the nearest intersection in any direction then it will attain a high value since it is the most central element within that area. This highlights the peculiarity of these network elements within the London network structure. It highlights the disconnection of the M25 from the street network for very large stretches. By using a form of analysis that highlights such phenomena we can observe the elements in the network that sit apart from the normative spatial structure of the city comprised of highly proximately inter-connected elements.

As the radius of analysis is increased from 800m to 10,000m in figures 10 to 14 the ever-increasing dominance of the central area of London can be observed. Whilst at 800m and 1600m radii of analysis the smaller centres of London can be seen, at the higher radii the whole network is dominated by central London. In space syntax terms what these maps illustrate is the polycentric nature of the city and how this changes across scales. As the scale of analysis is increased the smaller peak values disappear and larger more spatially homogenous areas of high integration emerge until at 10,000m radius of analysis the centre of London and arterial routes branching off and around the centre forms the peak of integration values (figure 14). It should also be noted that a quasi-deformed wheel structure, comprising of hub and spoke like structures in the urban grid, can be seen in figure 14, in line with previous analyses of London that were carried out on lower-resolution and geometrically distinct axial models of the street network. As mentioned in the previous chapter, this deformed wheel structure has been shown to be generic to urban systems worldwide (Hiller and Vaughan, 2007).

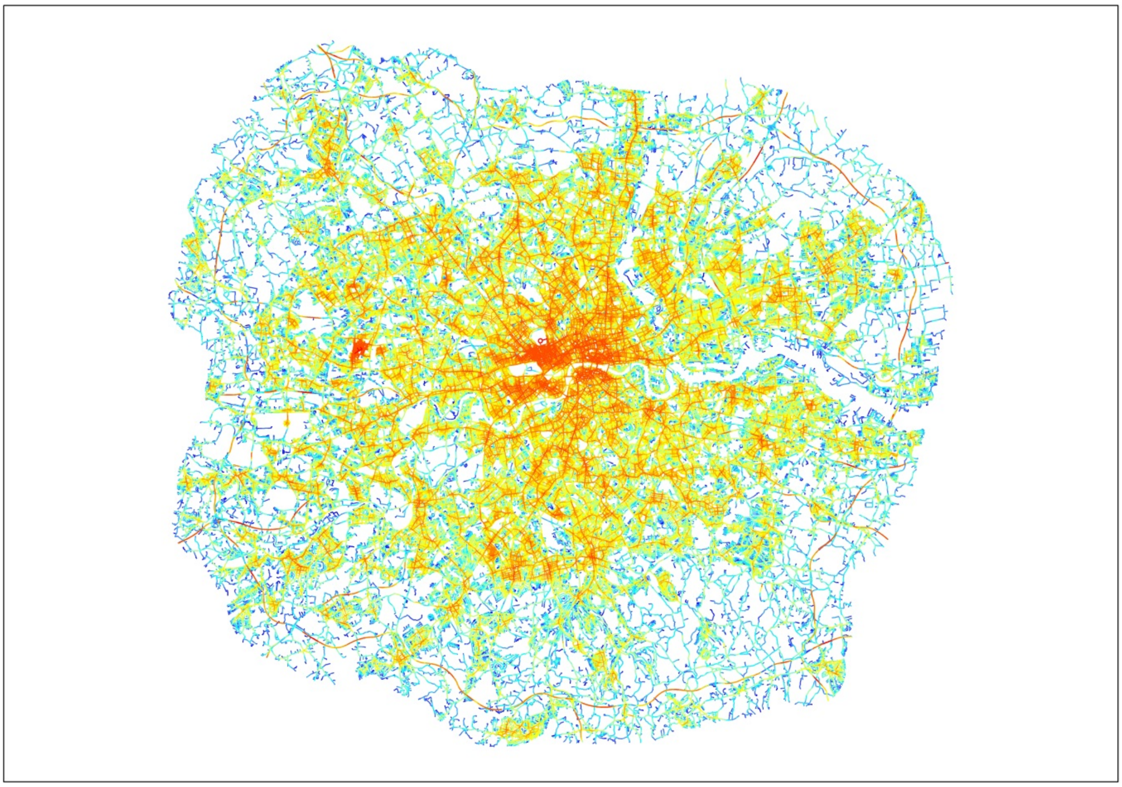


Figure 13 Integration radius 800m

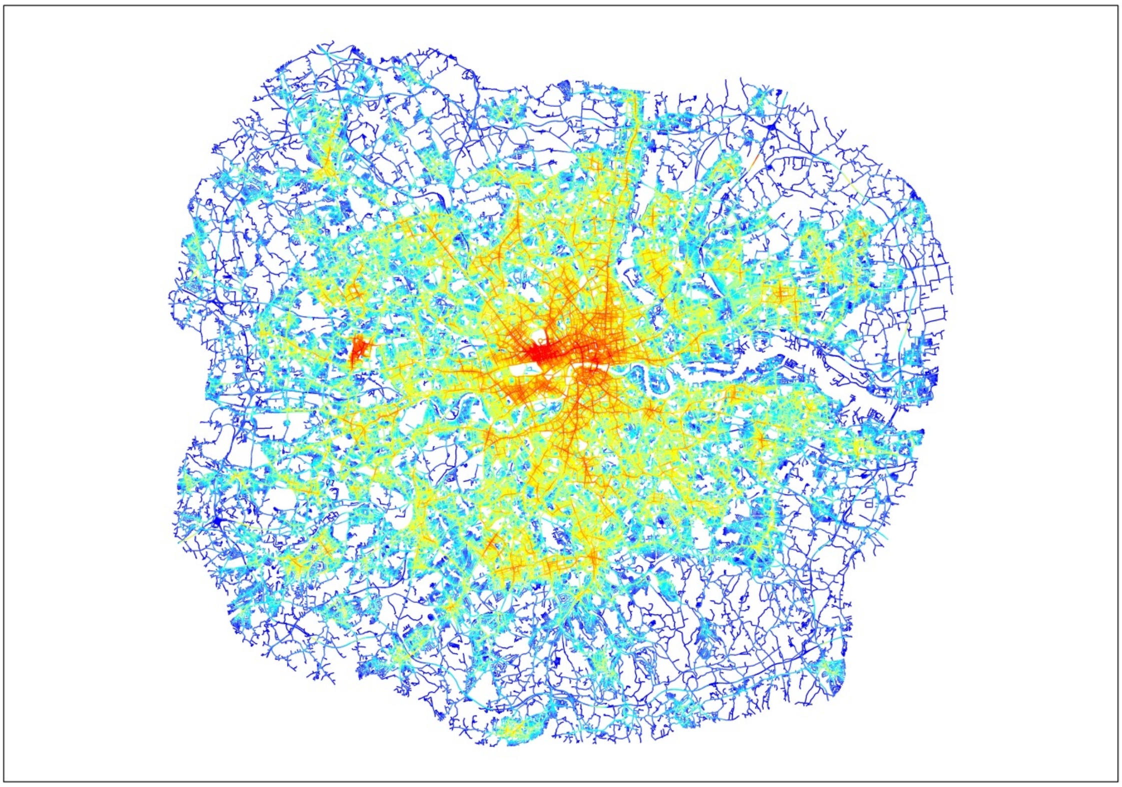


Figure 14 Integration radius 1600m

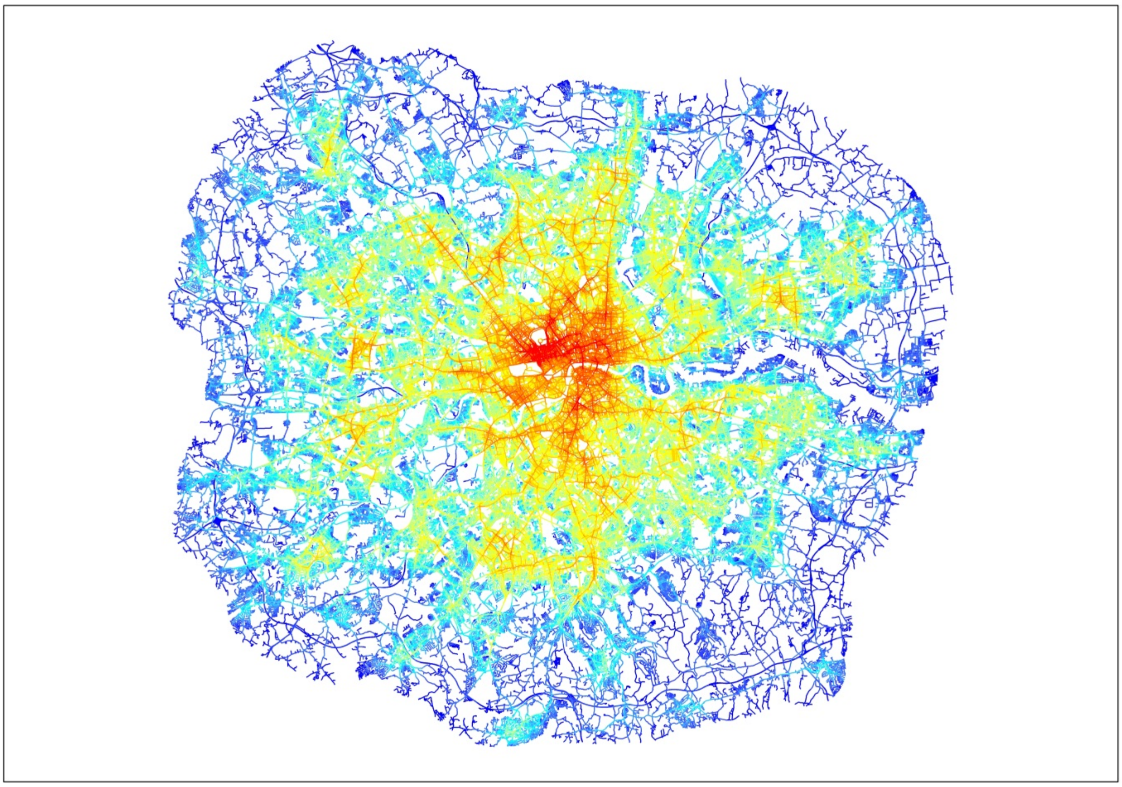


Figure 15 Integration radius 3000m

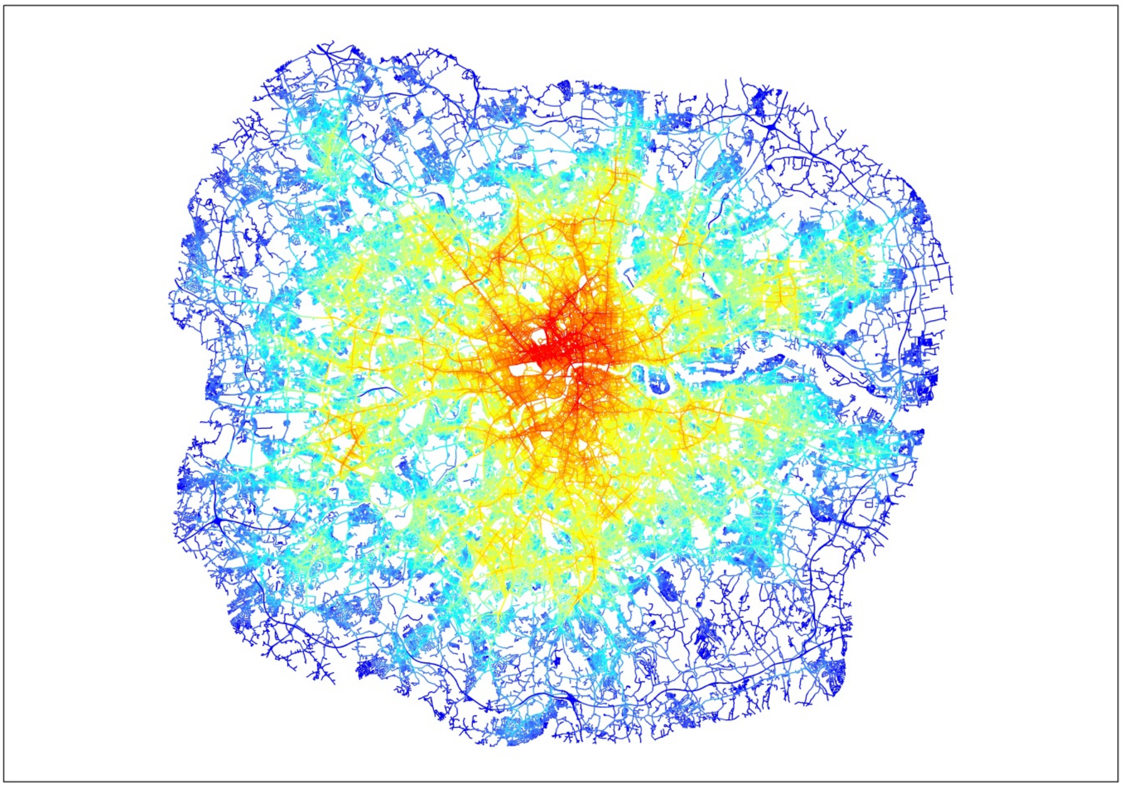


Figure 16 Integration radius 5000m

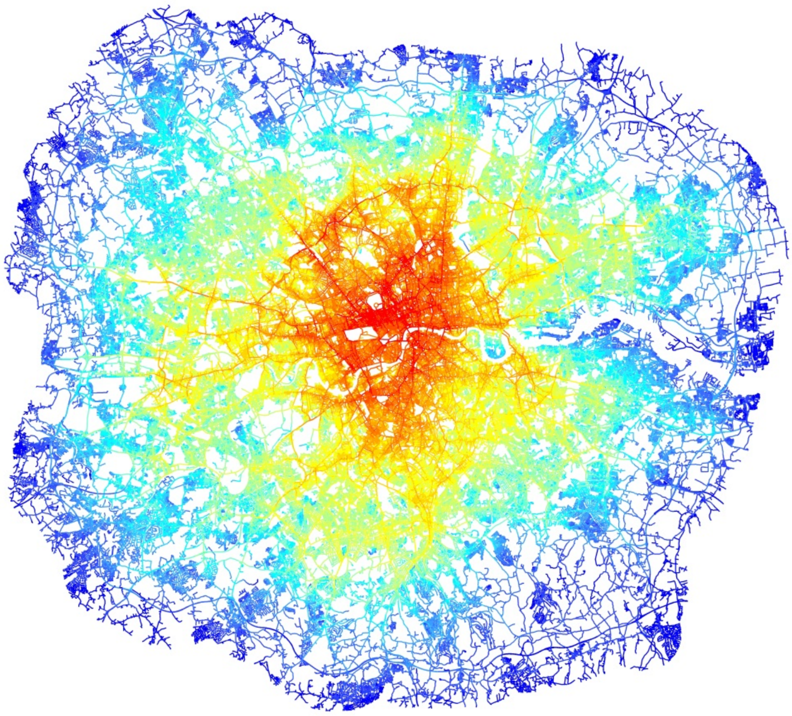


Figure 17 Integration radius 10000m

5.4.2 Angular Betweenness Centrality

The space syntax measure of integration captures the angular closeness and the simplicity of navigation to specific locations in the network and thus potential to-movement. In contrast, angular betweenness, referred to as *choice* within the space syntax field, measures the number of times that a network element is traversed on the shortest angular path between all other network elements within a specified radius of analysis. This measure captures the most likely location of flows of pedestrians and traffic through specific network locations. In figures 15 to 19 the same radii of analyses for choice are presented as in the previous integration maps; 800m, 1600m, 3000m, 5000m and 10000m.

As the scale of analysis is increased from 800m to 10,000m a similar but distinct change in the pattern of locations of high choice values in the network occurs. At 800m radius of analysis, locations of high values of choice are dispersed across many locations across the London region, reflecting again the polycentric nature of London built around spatially distinct localities that have developed and been subsumed into London as it has grown. As the scale of analysis is increased the shift that occurs is not the centralisation of higher values towards the centre of the London network, as with integration, but the centralisation of high values along the primary arterial roots spanning London. As can be seen in figure 19 there are few very high value routes that serve to connect London at this scale. The network as represented in figure 19 can be thought of as the primary foreground network of choice that structures movement flows across the whole city, whilst the network of choice at 800m (figure 15) and integration at 800m (figure 10) show the background network of local connectivity that is attached to this foreground network, to allow the structuring of movement across the city between differing scales. In relation to the case study town centres these qualities of the network are vital in providing both local and global network accessibility. Furthermore the convergence of both high integration and choice at specific radii should characterise its spatial situation in the network as a whole. The marked difference between the structure of choice and integration across scales shown in figures 10 to 19 illustrates the differences in the manner in which the two network measures characterise the network. Integration emphasises the central, angularly dense structures of the street network, whilst choice highlights the structures that connect areas of high density with one another. The relationships between the two are of great importance for town centres which function at many scales and are reliant on both proximity and accessibility for their success (Vaughan et al., 2010).

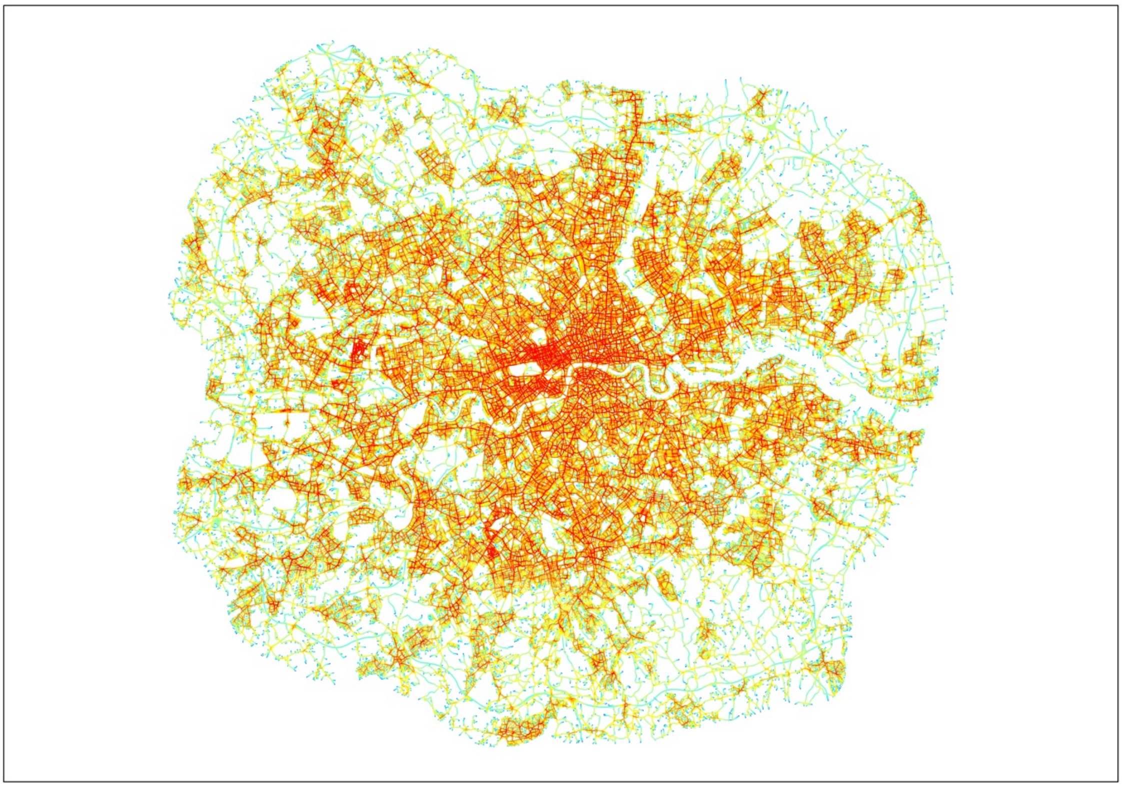


Figure 18 Choice radius 800m

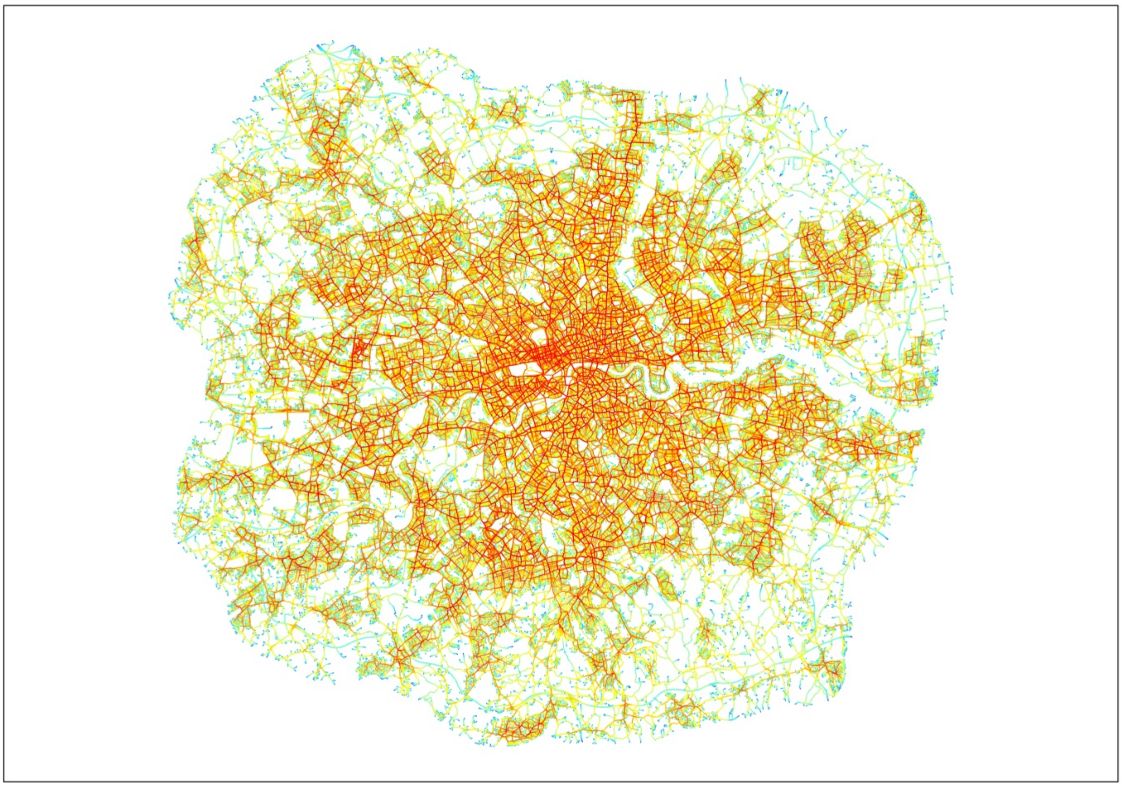


Figure 19 Choice radius 1600m

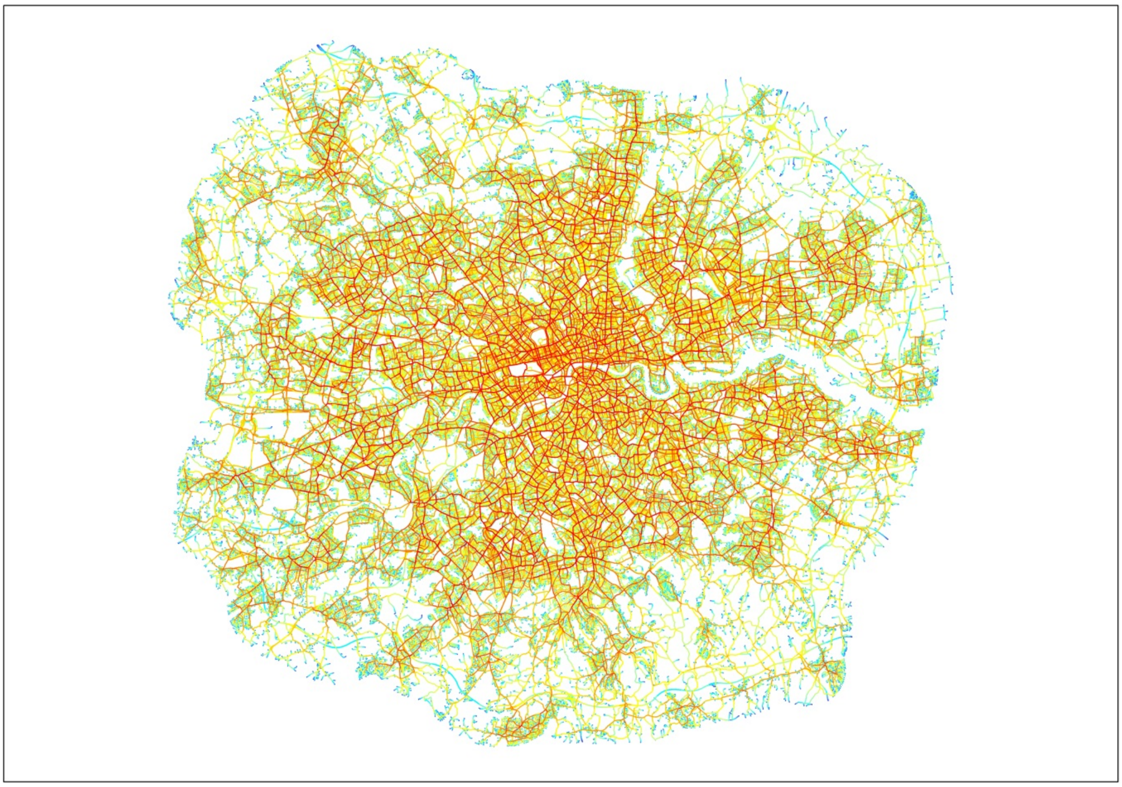


Figure 20 Choice radius 3000m

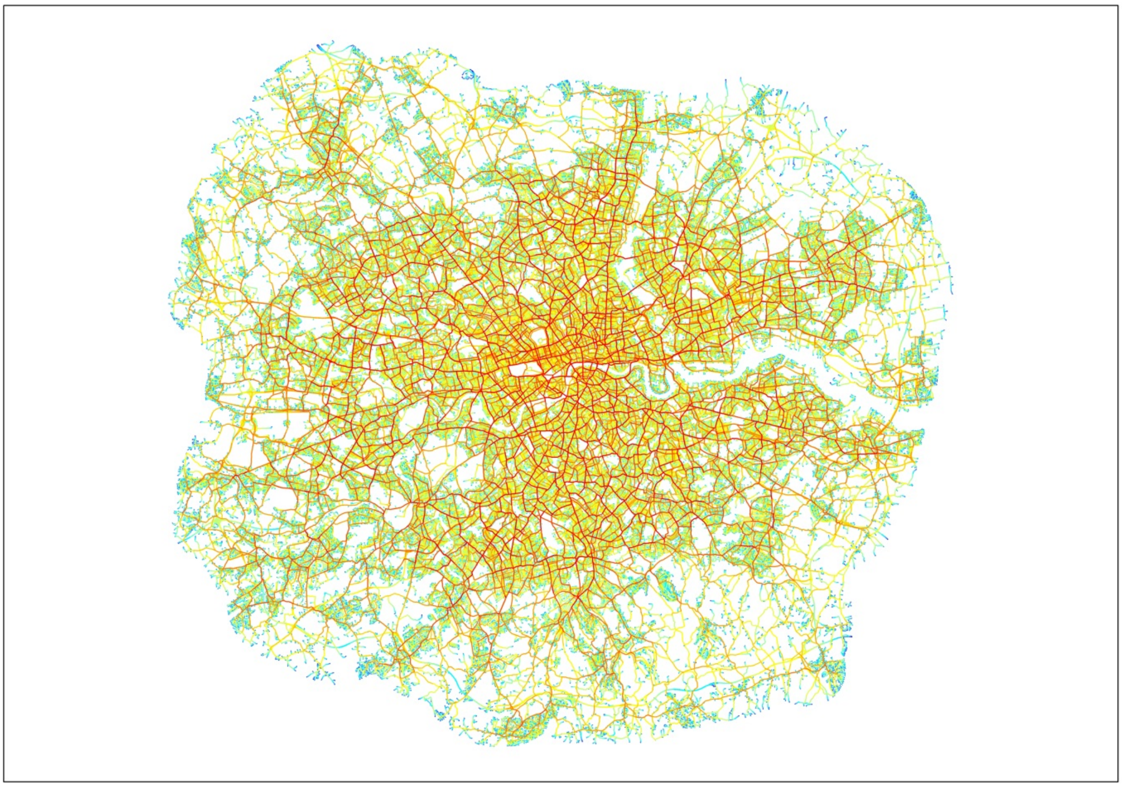


Figure 21 Choice radius 5000m

Figure 22 Choice radius 10000m

5.5 Peripheral case study centres versus centrally located sub-centres space syntax analysis

In order to understand the syntactic properties of the four case studies in regards to their peripheral position within the contemporary network of London, a comparative analysis of the four case studies in relation to four sub-centres in the centre of the London network is presented here. The four peripheral case studies are compared to Marylebone High Street in west central London, Upper Street in north central London, Shoreditch in east central London and Ludgate Hill in the City of London, shown in figure 23. The boundaries of these areas are derived from the GLA dataset described in chapter 3. The approach taken here is to look at both the values for choice and integration in relation to one another across the four case studies and the four comparative cases to observe the syntactic differences between central and peripheral urban centres. Within this analysis the through and to-movement potential that the network generates at different scales of analysis will illustrate the principal syntactic differences between the centre and periphery. This analysis aims to get towards an evaluation of urbanity in regards to the potential of the network to generate to- and through- movement. Within the context of the whole of London, locations that generate trips both to and through at large radii of analysis are likely to be locations of peak activity at the scale of the city, whilst locations with high values at lower radii will be more likely to form local centres.

Figure 23 Location of centrally located sub-centres used for comparison in relation to peripheral case studies

Graphs 6 to 10 show the relationship between choice and integration as the radius of analysis is increased in the eight locations being compared. The radii of analysis are the same as the maps of London-wide integration and choice (figures 10 to 19); 800m, 1600m, 3000m, 5000m and 10000m. In graph 6 the comparison of choice and integration at 800m shows that all eight cases have similar values and variance in both choice and integration, with the exception of High Barnet. The four central cases have slightly higher overall integration and peak choice values, Marylebone and Ludgate Hill having the highest values of both choice and integration of all the cases. The integration values of High Barnet show a particularly large variance with the lowest values of any case. The peak values for integration are at the same level as the other case studies but quickly fall away indicating a more singular core structure to the town centre network in High Barnet at this radius of analysis. Overall at the 800m radius of analysis it can be said that all the town centres, except High Barnet, show similar values for both choice and integration, indicating that their location within the network has similar potential to generate to- and through-movement at this scale.

In graphs 7 and 8 showing radii of analysis 1600m and 3000m a gradual stratification in the integration values of the eight cases can be seen. At 1600m the eight cases diverge between the four central locations with the higher integration values, and the four peripheral case studies with the lower integration values. Importantly this happens specifically in regards to integration; the values for choice maintain a similar pattern to the 800m radius of analysis where the four central cases have higher peak values but do not have higher values across all network elements. At this radius South Norwood is the exception of the four peripheral cases as it has notably higher peak values for choice, at the same level as the central areas.

The trend in the changes that occur between 800m and 1600m are further amplified when the analysis radius is increased to 3000m (graph 8). The four central cases have significantly higher integration values, whilst South Norwood's integration values occupy a middle position between the central and peripheral areas. The choice values in the case studies continue to remain stable in relation to one another. In graphs 9 and 10 showing 5000m and 10000m radius of analysis the trends that have already been observed continue; the four central cases centres' integration values group together with higher values than the four peripheral case studies, that also group together with similar integration values. South Norwood does not fit into either grouping and occupies a middle position between the two groups of integration value ranges. The choice values of the 8 cases across all radii are similar with only the peak and tail values differentiating between the central cases and the periphery with the exception of South Norwood that has peak choice values in line with those of the central areas.

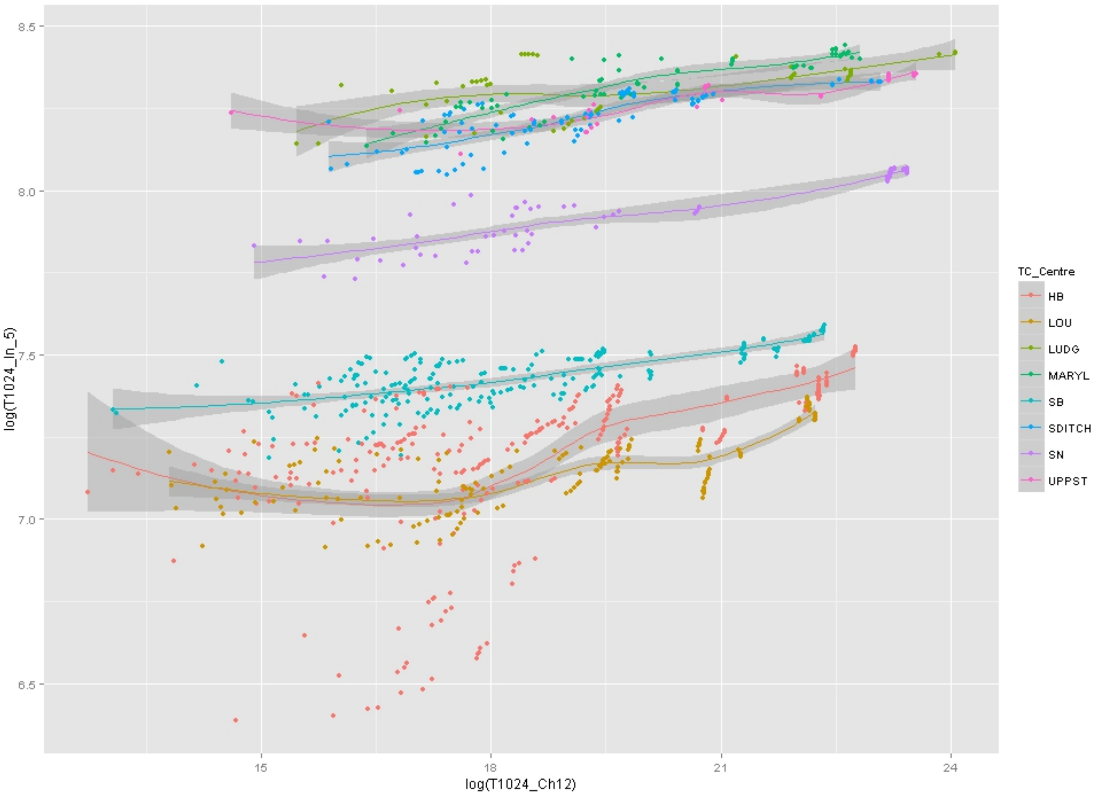
This analysis illustrates the syntactic qualities of the four case studies located on the periphery of the city in comparison to centrally located areas. It can be seen the primary differentiating factor between the centre and periphery in syntactic terms are the values for integration. Whilst at the local level of analysis all the centres are similar, as the radius of analysis is increased, the integration values in the centre continually rise relative to the peripheral case studies. This can be attributed to the density of the network in the centre of London and the comparative sparseness on the outskirts of the city. South Norwood is the exception to this, but as shown earlier it is the most densely built up network of any of the case studies, and it is the case study that is closest to the centre. This may explain its greater integration values than the other three case studies further from the centre of the city.

The main finding from this analysis is that the choice values remain stable relative to one another, and there is significant overlap between peripheral and central cases in the values of choice that they contain, both at the local and city scale of analysis. This indicates that their respective locations within the network of London generate similar potentials for through movement to occur. The presence of comparable potentials for large scale through movement suggests that centres in diverse locations in respect to the centre of the city contain the potential for both local and global flows. With future densification of the local area and the expansion of the densely built up core of London it is likely that these areas have the potential to attain similar levels of integration to the central areas today. It also highlights the local differentiation of the four peripheral cases, suggesting that they have different local conditions. The detailed variation of the local spatial structures will be explored in the next section.

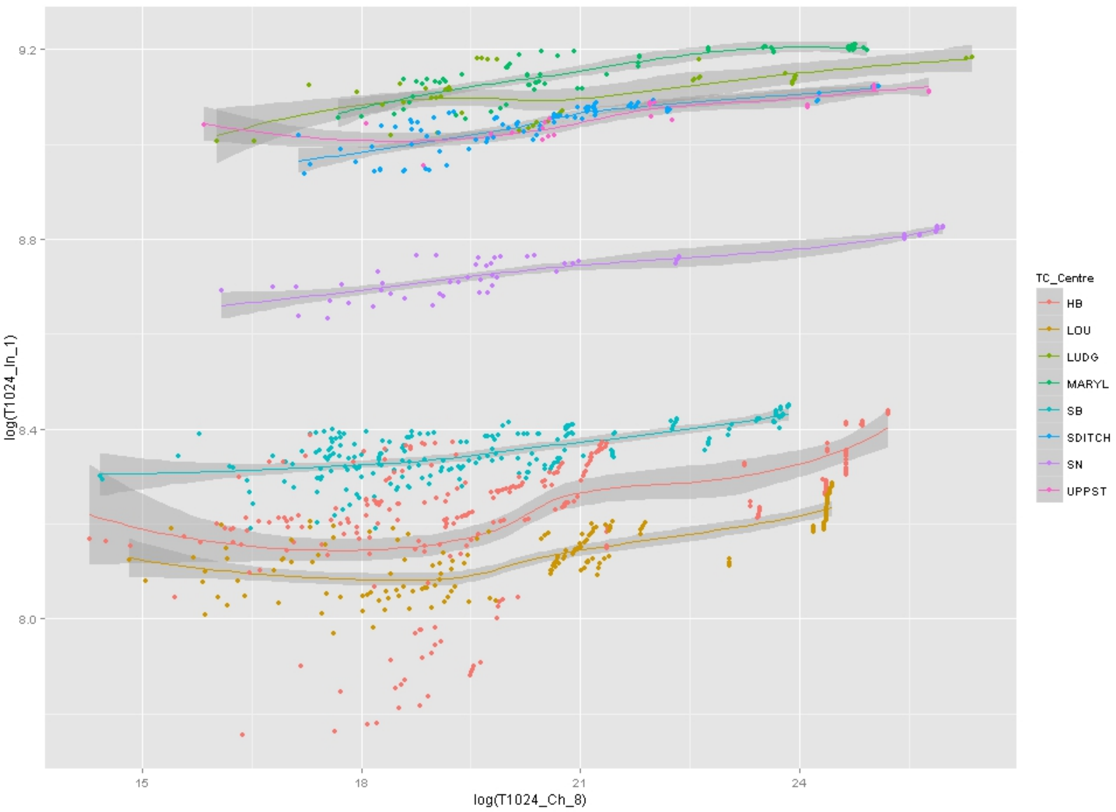
Graph 6 Choice radius 800m plotted against integration radius 800m

Graph 7 Choice radius 1600m plotted against integration radius 1600m

Graph 8 Choice radius 3000m plotted against integration radius 3000m



Graph 9 Choice radius 5000m plotted against integration radius 5000m



Graph 10 Choice radius 10000m plotted against integration radius 1000m

5.6 Summary

The analysis presented in this chapter has shown that the four case studies and London as a whole, have a diverse range of network characteristics that are revealed through different methods of network evaluation. Surbiton and South Norwood have the densest network of the four case studies, with Loughton and High Barnet having significantly lower densities. In relation to the whole London network and its subdivision, the four case studies have network densities in line with their spatial positioning in the overall network. When the network density of the case study areas is evaluated over time from 1880 to 2013 a steady increase is observed in all four cases, with the four case studies maintaining their relative levels of density in relation to one another. Taking into consideration the junction density, both in comparison to the whole London and network and through time the same trend of steady densification and relative density between cases and city-wide densification are observed.

The inclusion of dead-ends into the network evaluation through the computation of the ratio of junctions to dead-ends reveals a different pattern of development over time to the junction and network density metrics. This analysis reveals the form of the network development that has occurred over time, taking into account whether connective or exploratory growth is the predominant type. In this analysis it was shown that in the earliest stage of the network development covered in this analysis (from 1880 to 1910), the network became more connective as grid intensification took place and the ratio of junctions to dead-ends increased. In the subsequent periods of 1910 to 1960, and 1960 to 2013 this trend reversed and the ratio fell significantly. This change in the trajectory of the network development can be attributed to the change in the role of these locations in the context of London as a whole. With the expansion of networks of public transport and the desire to develop away from the perceived undesirable centre of the city rapid residential expansion on the periphery took place. As this residential expansion took place the network developed through exploratory growth, primarily through the subdivision of pre existing land parcels. This created a network with many dead-ends in relation to junction points, leading to the change in trajectory observed in the analysis.

In order to further the understanding of the structural properties of the London-wide network, space syntax were used used that to analyse the differing qualities of network integration and choice from the local to city scale. For the London network at the small radii of analysis integration was shown to capture a polycentric city comprised of multiple centres whilst at the largest radii of analysis, it demonstrated the core of integration occurring in the centre of the city and on radial routes. The choice analysis showed different properties of the street network to integration, the primary routes between local high integration centres were captured at the small scale, whilst at the largest radius of analysis the primary routes across the whole London network linking together the entire network were revealed. Whilst integration emphasised the core, network-dense structure of the central area of the city, choice showed the overarching network providing spatial accessibility across the whole network.

The London-wide space syntax analysis was then focussed upon the four peripherally located case studies in comparison to four central sub-centres. This analysis examined the relationship between choice and integration from the small, 800m scale through to the city level 10,000m scale. This analysis demonstrated that the distinction between periphery and centre is not clear-cut, but multi-faceted. In regards to the centres' integration, at 800m all eight centres showed similar levels of integration, indicating they held similar levels of potential for the generation of to-movement at this scale of trip distance. As the radius of analysis was increased the eight cases split into two groupings: those on the periphery with comparatively low levels of integration and the central cases with comparatively high levels of integration, with the exception of South Norwood that occupied a middle ground in regards to integration values. The levels of choice across the eight centres showed a different property of the network structures to the measure of integration. All eight cases maintained a range of choice values that was similar in all cases, across all radii of analysis. This indicates that the peripheral centres' configurational potential to generate to-movement through their closeness centrality, diminishes relative to the central cases as the radii of analysis is increased. Their location within the London street network at both the local and city scale has the potential to generate similar levels of through-movement due to their betweenness centrality. This is indicative of the lower density of network in the peripheral area, but alludes to a pre-existing framework of high choice network structures that can be the starting point for development in the future through greater connectivity and network densification as London grows and becomes more urbanised in the currently peripheral area of the city-region. It is the interaction and overlap of through and to-movement potentials, across a range of radii that creates the activities associated with town centres. How these potentials within the network have developed over time is the question that is addressed in the following section.

Key Findings:

- Different present-day network densities found in the four case studies although all show similar levels of increase over time, importantly maintaining their relative densities.
- The ratio of junctions to dead-ends in the network shows different stages to the network growth. Initially network development that created more connections took place, followed by exploratory growth that created many more dead-ends in the network.
- When compared to centrally located centres the four peripherally located case studies showed similar ranges of choice values, synonymous with through movement potential across all scales of analysis. However they showed drastically different integration values, synonymous with to-movement potential, with the exception of South Norwood that had values in the middle of the range between the peripheral case studies and the centrally located areas.

6 Historical Analysis of Street Network Evolution

6.1 Introduction

This chapter presents a detailed historical analysis of the changing structure of the street network through time, across the four peripheral London case studies of Loughton, High Barnet, South Norwood and Surbiton. In the first section, for each of the time periods that are used in this analysis: 1880, 1910, 1960 and 2013, maps are presented showing the angular betweenness centrality (choice) and angular closeness centrality (integration) values of the street network structures. The values that are shown in the first section of the analysis are for the smallest and largest radii of analysis, 800m and 3000m respectively. Only the largest and smallest radii of analysis are shown as this captures the local and sub-regional levels of street network structure; many intermediate values were also analysed but do not capture the spectrum of syntactic values of the network structures to the same degree as 800m and 3000m analysis radii. This analysis charts the evolution of the street networks in the case study areas as they have developed from peripheral settlements to parts of the semi-continuous urban fabric of London. Through this analysis an understanding of the competing spatial characters of urbanisation are captured, whether from incremental grid intensification or rapid city-scale infrastructural development. Understanding the nature of these processes enables a more holistic appreciation of the diverse ways that urbanisation of the peri-urban comes about and the implications for the structuring of movement potentials in the network, and thus for the spatial experience of daily life as understood through space syntax analysis.

In the second section further analysis of two of the case studies, South Norwood and Surbiton is carried out. These two case study areas were selected for further analysis due to their greater change over the period of analysis and more complete urbanisation. In this analysis the relationship over time between choice and integration values is explored. As shown in the previous chapter in the analysis of choice and integration for the whole London network, the two measures represent fundamentally different structures in the street network. The changing form of this relationship is examined over time to ascertain whether they are constant in their relational quantities or whether this relationship changes. Whilst this analysis is purely numerical the proceeding analysis looks at the spatial relationship between choice and integration. In this analysis the spaces in the network where the highest values for each overlap are mapped through time.

The analysis presented in this chapter aims to obtain a wide understanding of the network development of the case studies. Through this analysis the genesis of the case studies can be understood in regards to their contemporary relationship to the whole London street network, as analysed in the previous chapter. Of particular importance to this analysis is developing an understanding of the spatial nature of change, and the type of movement that spatial network change engenders in the network. Importantly, the analysis addresses the question as to whether London's century-long growth enabled increased movement to and through the case study areas, or served a different spatial purpose in the development of the city's region.

6.2 Methodology

In order to create a time series of network representations of the four case studies' street networks for the four historic periods between 1860 and 2013 a method called 'cartographic redrawing' (Pinho and Oliveira, 2009, Serra and Pinho, 2011) was employed. As explained in the Data Appraisal and Methodology chapter, this is necessary due to the space syntax analysis techniques that are used requiring a vector line based representation of the street network and the historic map data only being available in raster image format. Cartographic redrawing is a method that allows for the non-destructive creation of chronologies of urban morphologies.

The process is carried out from the contemporary period backwards with the most accurate contemporary vector street network data from the UK Ordnance Survey national mapping agency forming the basis of all the historic street network representations. The contemporary vector line data is overlaid on the historic mapping for the first preceding period under investigation and all sections of road are deleted that are not present in that period, so that the street network matches the previous period. This is repeated for each preceding historic period for which the street network is required, creating an individual layer for each period. This is carried out on a circular area that extended 6km beyond the contemporary town centre boundary. The total size of the area that this process was completed for is 452km^2 across the four case studies for the four time periods, as shown in the previous chapter.

The two space syntax measures that are used here are choice and integration angular segment analysis. These measures are variants of betweenness centrality and closeness centrality, measures that are commonly used in network analysis. The specific measures that are used are angular segment segment-length weighted choice to account for the utilisation of a road centre-line network model (see chapter 4) and angular segment integration. The results are presented for a central 3km radius around the town centre and the maximum radius of analysis is 3000m, whilst the analysed network extends 6km beyond the town centre. The larger contextual area was included to avoid edge effects that occur when the radius of analysis is set. It was selected such that any segment being evaluated is within this distance from the edge of the network model.

Further analysis of Surbiton and South Norwood is carried out that examines the changing values of choice and integration through time and the spatial relationship between locations of high choice and integration. The measures of choice and integration are combined for Surbiton and South Norwood across all time periods to identify the line segments that spatially overlap in the values of choice and integration). This is referred to as co-presence (Vaughan et al, 2009; Vaughan et al 2010; Dhanani and Vaughan, 2013) as it capture the areas of highest through and to-movement potential and thus the locations in the network where they are structured such that the highest probability for encounter occurs (as first laid out in Hillier et al, 1987, with reference to axial choice and integration). The analysis of the numerical and spatial relationship between choice and integration relates back to the previous chapter's analysis of the relationship between choice and integration in the contemporary city, which proposes that where they come together allows different types of the movement to occur and the greatest potential for utilisation of land to exploit the movement that could come about. Previous research has suggested that the location of greatest overlap is likely to be where the centres of the potential for the products of the movement economies of the city can take root, termed by Vaughan et al. (2009) the 'active centre'. This concept of co-presence is also evaluated mathematically through correlations of choice and integration between all scales of measurement, following the method laid out in Vaughan et al 2009. The radii of measurement that correlate most highly can be said to show coherence between the scales, which through and to movement are operating at. The differing relationships between scales are another important factor that can be evaluated through this methodology. The analysis of co-presence is carried out through time to ascertain the changing peak locations of co-presence in the network.

6.3 Historical Space Syntax Analysis

This section presents the results of the space syntax analysis of the changing structure of choice and integration for the four case study areas. The network analysis that is presented is for the central 3km radius around contemporary the town centres. In all case studies it was found that the average values for choice alternated over time with a net fall in value, but the highest values consistently increased, as did the standard deviation (see figure 6). Integration on average increased over time across all scales in both case study areas, as did the highest value and standard deviation (see figure 5). Whilst these trends can be understood as the process of urbanisation it must be considered within the suburban context whether the morphological development of suburbs in the inter-war and post-war period exhibit unique spatial properties.

6.3.1 Loughton

In the Loughton study area the total road network length increases over the period from 75.8km to 203.3km within the 3km area of analysis. This represents an increase in the density of road network per square kilometre of 3.7km over 130 years, reaching the current density of 5.9 kilometres per square kilometre. In figure 1a the measures of choice and integration (left and right respectively) at 800m radius of analysis are shown. They are shown next to each other to highlight the different structures that the two measures emphasise and how they co-evolve over time. They are in sequential order from top to bottom; 1880, 1910, 1960 and 2013. In figure 2b the same time sequence is shown but the radius of analysis is increased to 3000m. From these figures it can be seen that the street network in and around Loughton is neither continuously nor evenly spread across the space. The large open area to the north-west is the protected Epping Forest, as mentioned in the previous chapter, which constrains the growth of the network. Overall the network around Loughton can be said to be constrained in its development and forms a lobe-like area of street network extending from the southwest to the northeast. The street network does not form a continuous system in any of the time periods and in 2013 it is still an isolated network structure with few links to the wider street network.

In 1880 at 800m radius of analysis (Fig. 1a) the street network is extremely fractured, with many large open areas where there is no formal or public infrastructure to access it. The highest value for choice mainly concentrates around the Buckhurst Hill area in the south of the analysis area, with other peaks in the values occurring in northern and western locations. Loughton itself has some locations of higher values but relatively it does not contain the peak values for choice in the earliest period, furthermore the higher values are not concentrated but spread along the length of the axis running south-west north-east through the centre of Loughton. In terms of integration in 1880 a similar pattern to choice is present but with a more continuous concentration along the central axis running through the centre of Loughton. In the maps showing the integration values it is important to note the extremely high values that appear on isolated segments at 800m radius of analysis. This is the result of its isolation within the network. This is an important consideration methodologically when using space syntax analysis in areas with spare grid systems. This is not observed at 3000m radius of analysis where the distance is large enough to encompass all the segments within the analysis area. At this scale of analysis the network's overall structures of centrality can be seen. The highest choice routes through the network extend north, south and northwest connecting between the areas of highest grid density. Notable is the lack of any strong connection in the easterly direction. The structure of integration does not mirror the structure of choice as at 800m radius of analysis. At 3000m (figure 1b bottom) the concentration of integration is primarily in the southern area around Buckhurst Hill and extending up to the junction in the north. The primary difference that can be observed here is the importance of the route through the forest in the north-westerly direction for choice but not being as significant for integration. This indicates that although it is an important route for through movement it does not function as to generate to-movement in the grid. This is logical in that it is a link through the forested area that has very few junctions or locations of high grid density.

In the period 1880 to 1910 the changes that occur at 800m radius of analysis are incremental, mainly focussed on the main axis through Loughton. Here the development of more connecting roads around the centre increases both the values for choice and integration that occur there. This early stage of grid intensification around the centre of Loughton brings up the levels for both choice and integration to those of the surrounding network centres. These changes are all brought about by the increased local connectivity as the grid structure is reinforced around pre-existing centres. One area on the south-western edge becomes a centre of both high choice and integration at 800m due to the development of dense grids and a connecting through-route in an area where there were no dense street grids or direct connections to the main north-south routes previously. At radius 3000m the change from 1880 to 1910 is also mainly incremental in that the values for integration spread northwards from Buckhurst Hill into Loughton and the values for choice, as at 800m form a continuous peak along the axis through the centre of Loughton. The exception to this incremental change is the new road connecting the newly developed dense street grid on the south-western edge. This new element within the street network is now a route of high through movement potential. This illustrates the impact of small changes on large-scale network properties.

The principal changes in the development of the street network and its structures of centrality occur in the subsequent period from 1910 to 1960. In this post-war period the biggest changes of any time period take place. Loughton experiences extensive development of the street network through expansion to the east. This expansion creates many new centres and routes of choice and integration at both 8000m and 3000m radius of analysis. At the 800m analysis radius the main route through Loughton becomes highly central in regards to choice and the development of the grid to the east causes the route to the southeast to gain high choice values. This is also reflected in the integration values that are high along this route, furthermore many new centres of high integration develop in this area where the previously empty space has been urbanised. This extensive grid intensification reflects the period when suburban development on the periphery of London took-off. This pattern is directly reflected at

3000m radius of analysis where the same routes also become highly central in terms of choice and integration values. This stage in the development of the street network and the urbanisation of Loughton entirely reconfigures the structures of network centrality in the area. Previously the main structures lead in a north-south orientation, but following the development that took place between 1910 and 1960 Loughton becomes the central focus of the network within the area and creates strong linkages to the east that were not previously present. Whilst most urbanisation is seen as incrementally augmenting the pre-existing structures that are already in place, from Loughton it is clear that rapid development in new areas both occurs and changes the spatial structure in ways as to reconfigure both local and regional spatial relationships. The lack of more development in areas on the northern and eastern edges of the network means that the primacy of Loughton is enhanced and the connection through the forest diminish in relative importance.

From 1960 to 2013, as in the period from 1880 to 1910 the changes that take place are incremental with the exception of the introduction of the M11 motorway running along the south-eastern edge of the study area. At both 800m and 3000m radius of analysis the main centres of high choice and integration values remain largely unchanged with only small changes occurring due to further grid intensification in locations with already-dense grids. The introduction of the M11 motorway does not have particular significance at 800m since the structure is so disconnected from the existing network that it is not central at this scale of analysis, even at 3000m radius of analysis this structure is of little importance in terms of centrality values. This is a remarkable outcome that such a significant infrastructural development has had such little local impact. The lack of local impact brought about by the M11 highlights the spatial purpose of the motorway; it was not developed to increase local connectivity but was intended to increase city-scale connectivity. Whilst the local area can easily access the motorway through proximate linkages the motorway itself does practically nothing to alter the local and sub-regional spatial characteristics of the area.

Throughout the entire period covered by this analysis the most significant development of the network and urbanisation takes place in the period from 1910 to 1960. During this period Loughton grows dramatically and the structure of centrality is radically altered. The other major change is the development of the M11 motorway but this has little impact of the syntactic structure of the area at either 800m or 3000m radius of analysis. Up to the present day the network of Loughton is isolated and has not developed into a fully en-meshed part of a continuous urban street network apart from at the southern most end. Nevertheless the spatial development of the area over 130 years had consolidated the structures of centrality around the historic core of the settlement at both the local and wider spatial scale. Through this consolidation over time the potentials for through and to movement through the centre have been maintained, ensure it has the potentials to act as an active centre for the surrounding community.

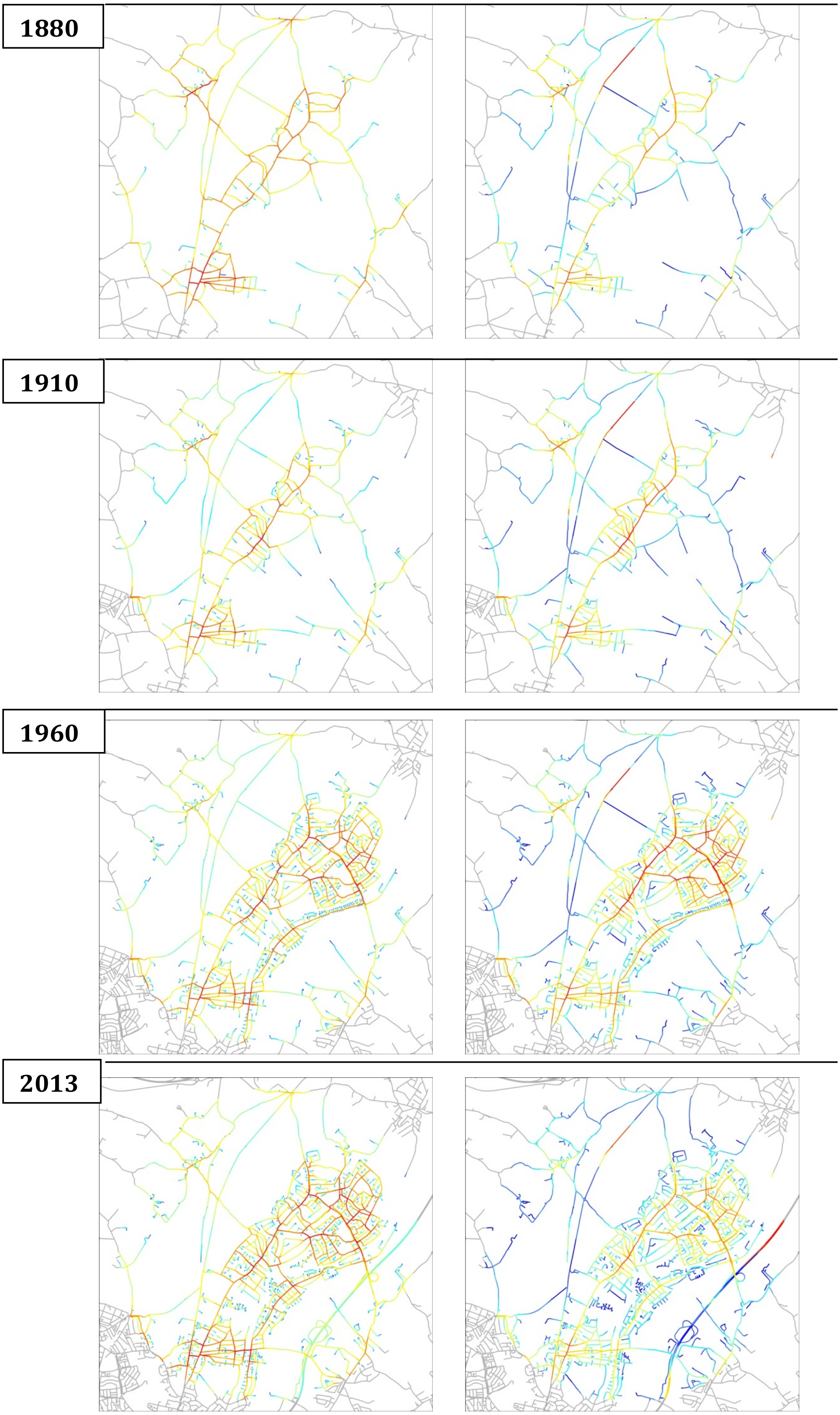


Figure 1a Loughton Choice (left and Integration (right) radius 800m

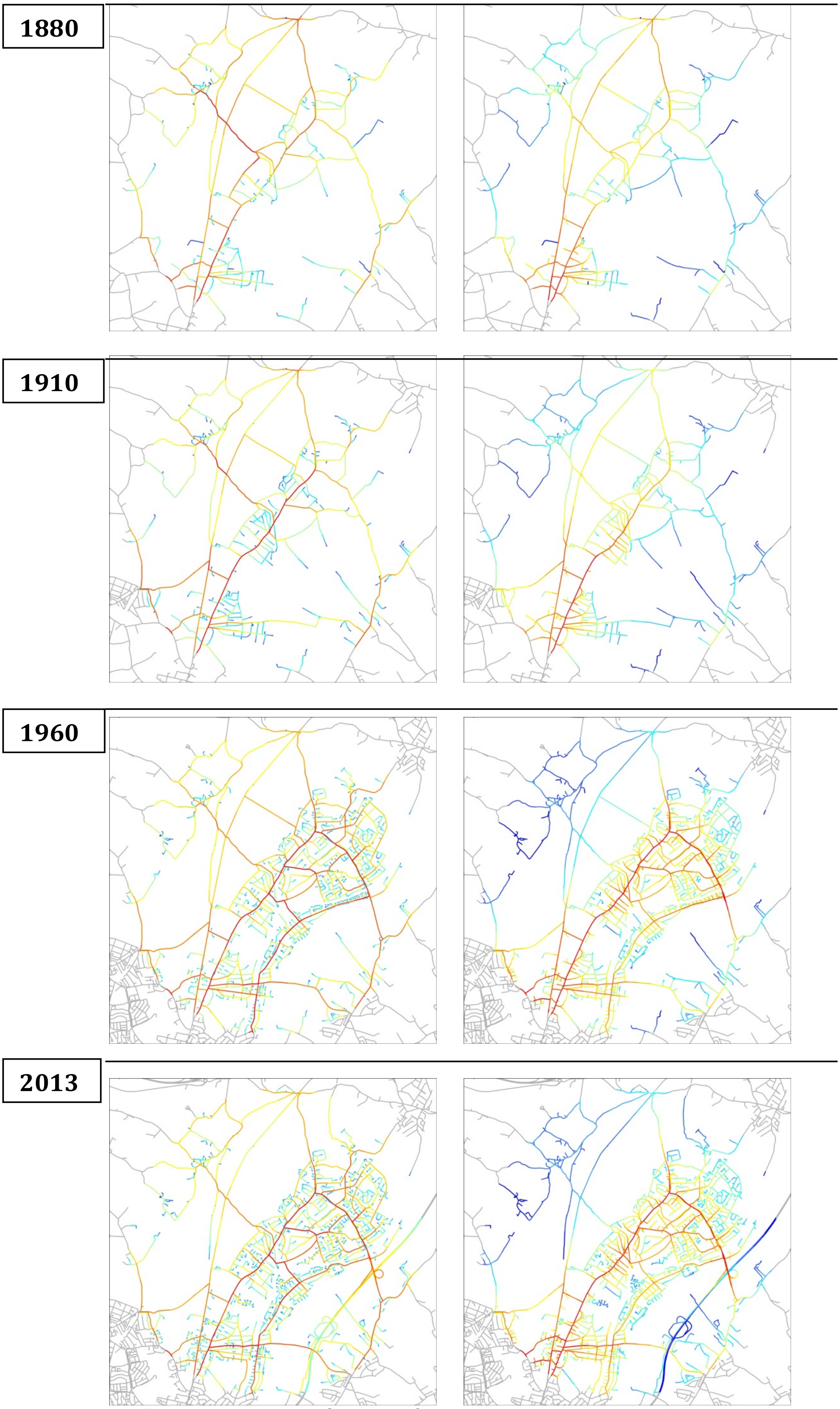


Figure 1b Loughton Choice (left) and Integration (right) radius 3000m

6.3.2 High Barnet

In the High Barnet study area the road network length increases from 72.15km to 202.7km from 1880 to 2013. This represents an increase in road network density of 3.8 kilometres per square kilometre over the 130-year period reaching a density of 5.9km/km^2 in 2013. In figure 2a the structure of choice (left) and integration (right) values at 800m radius of analysis are shown in sequential order; 1880, 1910, 1960 and 2013 (top to bottom). In figure 2b the same sequence of maps are shown with the choice and integration values for 3000m radius of analysis shown. From figure 2a and 2b it can be seen that similarly to Loughton, the street network in the High Barnet study area does not develop either complete or even coverage of space by 2013. The network in 2013 is still relatively isolated amongst large areas of open space traversed by few network elements. The isolation of these routes is highlighted by the high values attributed to the isolated segments in the 800m choice analysis images. Through the whole time period the network development to the east of the study area, in the area today known as New Barnet, is the main focus for development and the values for choice and integration reflect this as multiple areas are shown to be syntactic centres across all scales in this area. Apart from the street network development in the southeast large areas remain undeveloped with little to no network development occurring.

In 1880 the street network is sparsely developed with only one area of dense grids in the southeast. The principal structures of the network are three routes in north, west and south-easterly directions. These are highlighted in figure 2b as being the primary routes of high choice. The structure of choice and integration at 800m highlights the two local centres of high centrality present in 1880 around the centre of High Barnet and the area of dense grids to the southeast. From 1880 to 1910 the principal development of the network takes place in the south east of the study area, closest to central London. The small area of dense grids that is present in 1880 expands to create a larger area of high grid density. At 800m radius of analysis that reinforces and brings to the foreground the high choice route that runs from the south east to the centre of high Barnet. The structure of integration is not changed but supplemented with more local centres within this new area of high grid density. At 3000m radius of analysis the values for choice are shifted from emphasising the through-movement potential of the routes to the northern edge of the study area from the centre, to the route leading southeast. The structure of integration at 3000m radius of analysis also reflects the dense grid development in the south east of the study area by highlighting the primary routes that traverse the newly developed dense grids.

From 1910 to 1960is the period that had the most significant street network growth. The street network develops primarily around New Barnet as in the previous period and to the south of High Barnet. At 800m radius of analysis the development to the south of High Barnet brings about the creation of new centres of integration and routes of high choice. This is caused by the development of routes connecting the east-west routes to the south of High Barnet with the east-west route in the centre of the study area. These connections act to create a loop connecting between the main pre-existing routes of high choice and integration at 800m radius of analysis. At 3000m radius of analysis the new connections do not have a significant impact on the structure of choice other than re-enforcing the primacy of the primary routes already in place. Integration at this scale is directly affected by the new network connections to the south of High Barnet and new locations of high integration emerge. The continued development of New Barnet in the east of the study area affects both choice and integration structure at both scales of analysis. The continued densification and expansion of the street grids in this area creates many locations of high choice and integration at both 800m and 3000m radii of analysis.

Despite local intensification the changes that take place between 1960 and 2013 in the street network are marginal and have little effect on the structures of choice and integration at either 800m or 3000m radius of analysis. As can be seen in figures 2a and 2b there is hardly any noticeable change in the principal structures of centrality. The main stage of growth that the High Barnet study area experiences is in the period from 1910 to 1960 with most of this development being focussed on the area of New Barnet in the south-east and the area directly south of High Barnet itself. The name of New Barnet seems fitting in the context of this analysis, as it is the area that experiences all the growth during the period of study. High Barnet itself does not expand or develop significantly in any area apart from the south, which is not directly adjacent to the core of the settlement that was present in 1880. The area of New Barnet in comparison to High Barnet is in fact new and also accounts for the vast majority of the new network development and areas of high choice and integration that emerge over the period of study. Despite the majority of development taking place in this area the centre of High Barnet has retained its centrality across scales within the structure of the network enabling its continued function as a location of high movement potential.

Another key theme in the syntactic development of the High Barnet area that can be seen is the shift from north to south of some lower level areas of high centrality. On the northern edge of the study area in 1880 at radius 3000m of analysis there are high choice and integration locations within the network, but as the network develops in the southeast the emphasis of centrality moves away from the northern area to the south. Whilst in 1880 High Barnet and the surrounding area were isolated areas of development outside London, over time they became fringe elements of London. As this took place the emphasis for development was biased in the direction of London leading to a re-orientation of the structures of high centrality towards the centre of the city in a southerly direction where the emphasis of development took place.

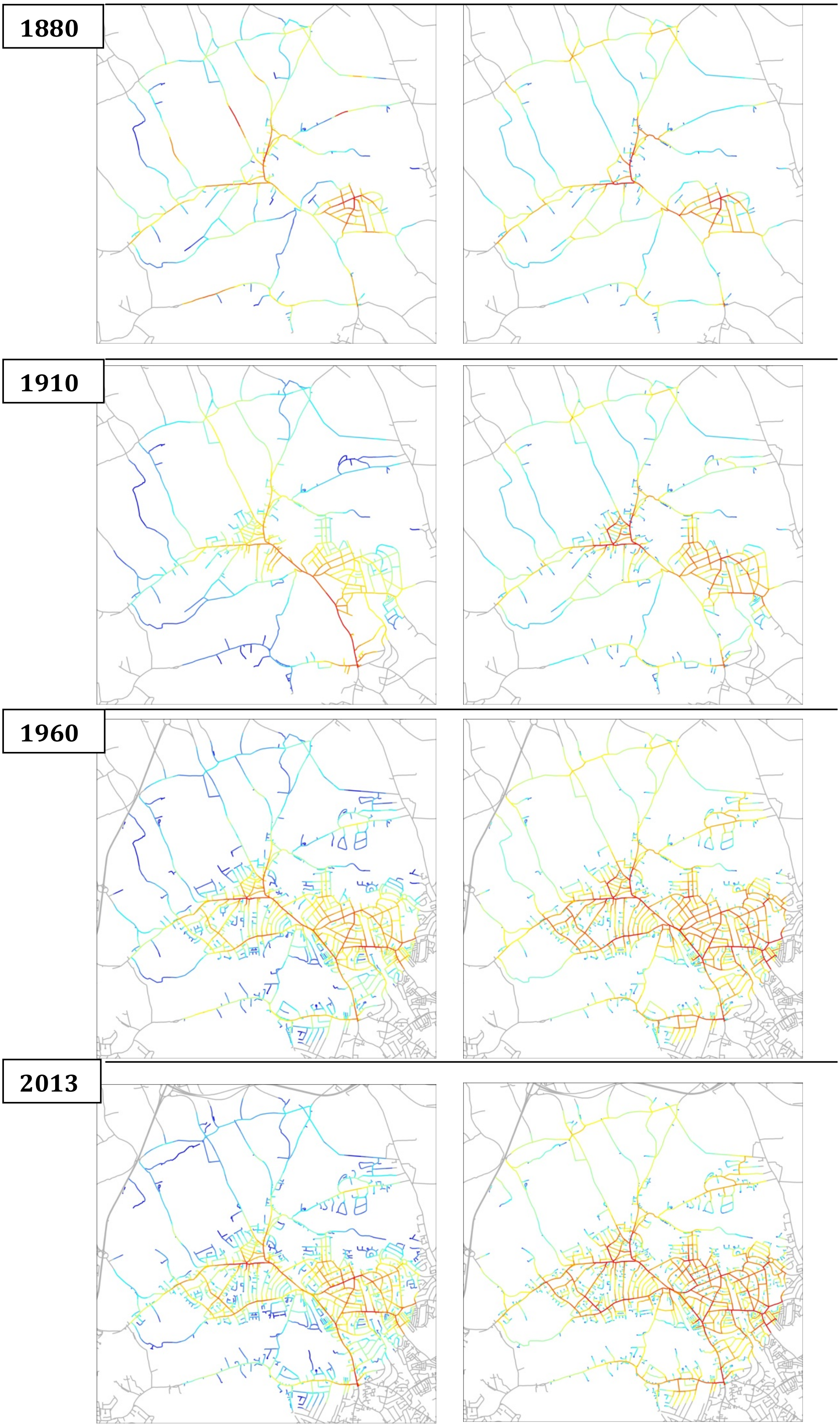


Figure 2a High Barnet Choice (left) and Integration (right) radius 800m

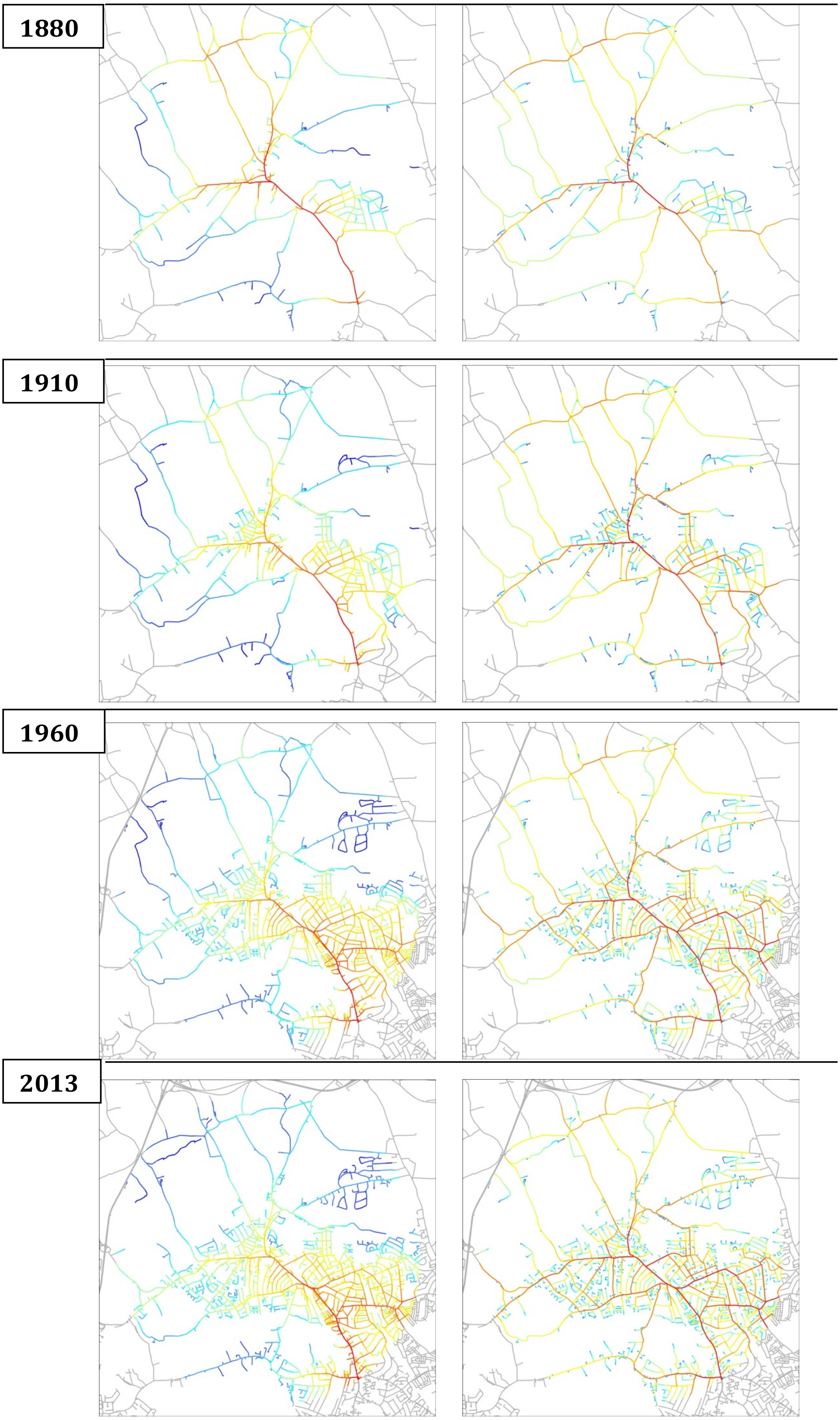


Figure 2b High Barnet Choice (left) and Integration (right) radius 3000m

6.3.3 South Norwood

In South Norwood the total road network length increases over the period from 156km to 430km within the 3km area of analysis. Figure 3a shows the values for choice and integration at radius 800m in the South Norwood study area for the four time periods of 1880, 1910, 1965 and 2013 in sequential order (top to bottom); Figure 3b shows the same sequence for 3000 metres radius of analysis. From these figures it can be seen that the morphological evolution of the area follows a pattern. That builds upon and between previous structures of choice and integration to reinforce and enlarge them, and the creation of new centres at both local and regional scale. Furthermore there is a clear and temporally persistent spatial divide between two regions of the study area.

In 1880 at 800 metres radius of analysis (Fig. 3a) multiple local cores of integration that are weakly linked together can be seen across the sparsely populated grid which contains many areas that the street network does not enter; the principle concentrations of choice are in the present day locations of Croydon in the south-west, South Norwood in the centre and Crystal Palace in the north. The structure of choice in 1880 at radius 800m closely reflects the structure of integration in the location of the highest values. This suggests that the through and to movement potentials at this scale may be spatially coincident in this period indicating locally coherent systems of through and to movement existing across the space but not relating to one another strongly. In the same time period at radius 3000m of analysis as shown in Figure 3b there is a dominant integration core in the southwest around the area of present day Croydon. The other locations of high integration are in the centre of the map around present day South Norwood and Crystal Palace on the northern edge of the case study area, but they are comparatively weak. Choice also peaks in the same locations, but is highest in the connecting routes between integration cores rather than the more densely connected streets around the locations of highest integration. This shows how the choice and integration reflect one another through reflecting the configurational properties of the network to structure to and through-movement into one coherent system.

As the network develops from 1880 to 1910 at radius 800m and 3000m, the network elements of the highest centrality in 1880 increase their relative centrality to the rest of the network making them more prominent centres. This is through the densification of road network around the pre-existing centres thus increasing their integration and leading to choice between these centres concurrently increasing. The one exception to this is the emergence of another integration core and through route of choice on the western edge at 800m radius of analysis, forming a secondary local centre on the same linear route that runs from the centre of Croydon to London along a road of Roman origin. This local centre is not reflected in the 3000m analysis radius indicating that whilst it has developed locally over this period as a strong local centre it has not been incorporated into the larger scale structures of centrality.

Between 1910 and 1960 at radius of analysis 800m the pre-existing centres are further developed into wider reaching and more centrally concentrated centres. The notable exceptions to this trend are an area on the eastern edge that develops as a local integration core and locally high choice area due to the dense build-up of street in the area; although similarly to the centre that emerged in the preceding period on the western edge it does not feature at the 3000m radius of analysis. The centre on the western edge that developed in the 1880 to 1910 period now features prominently at the 3000m radius of analysis as it has densified and become structurally influential at the 3000m scale. At radius 3000m metres it can also be seen that the route running along the southwest of the study area linking Croydon to London has been significantly densified and numerous side roads are prominent at 3000m radius integration.

Between 1960 and 2013 at radius 800m the principal changes occur around South Norwood and Crystal Palace; here the network is densified to a greater degree over the period than the Croydon-London route creating strong local integration. The other significant change in this period at the 800m scales is in the south western corner where an offset in the linear structure of integration occurs. This offset is due to the introduction of an elevated roadway connecting into the centre of Croydon that reconfigures the local area. At radius 3000m metres the changes are more dramatic in their impact; the previously highly integrated area around the London-Croydon route is no-longer the most prominent integration core; this has now moved to areas around South-Norwood and Crystal Palace where there has been a strong increase in the density of the road network around the centres. Whilst Croydon in the period 1910-1960 densified greatly, in the period 1960-2013 the other centres experienced a spurt of growth that has led to regionally more prominent centres. The movement in the centres of integration could be the result of the Croydon-London route being densified to the point where it cannot densify anymore, whereas the other areas can continue to grow, as they have not reached such a level of density. Also notable is the area on the eastern edge that developed strong local choice and integration has not developed in the same manner in the subsequent period that the centre on the western edge did; it is still prominent locally but not at the regional scale.

One spatial theme that can be seen to run through this entire time series analysis is the difference in syntactic properties of the north western half and the south western half. Throughout the time period of the analysis the south eastern half has only one locally strong centre develop at radius 800m analysis and no significant centres at radius 3000m of analysis. It also does not have any strong routes of choice connecting across or within. It also contains the most locally and globally segregated areas within it. These areas are suburban housing estates that have been built in such a manner as to create circuits of segregation that do not have any impact on local properties of the grid since they are primarily composed of curvi-linear dead-ends. The build-out of the area also only gathered pace in the period 1910 onwards; in comparison the other areas of the network that had some form of spatially established centres in the earliest period of 1880. From this it could be said that South Norwood is actually a morphologically divided area. Significantly the divide occurs very close to the train line that runs through the area, bringing to mind the cliché of ‘the wrong side of the tracks’. In this instance that cliché may refer to the being on the wrong side of the tracks when the growth of the area took place and the associated planning ideologies of the period. The north western half experienced growth prior to the development of spatially segregated ideologies of suburban domesticity, locking it into a more spatially integrated mode of development. Considering the character of South Norwood’s town centre on the ground, this spatial disjuncture could have contributed to its lack of success due to the fragmentation of local accessibility and potentials for converging patterns of through and to movement.

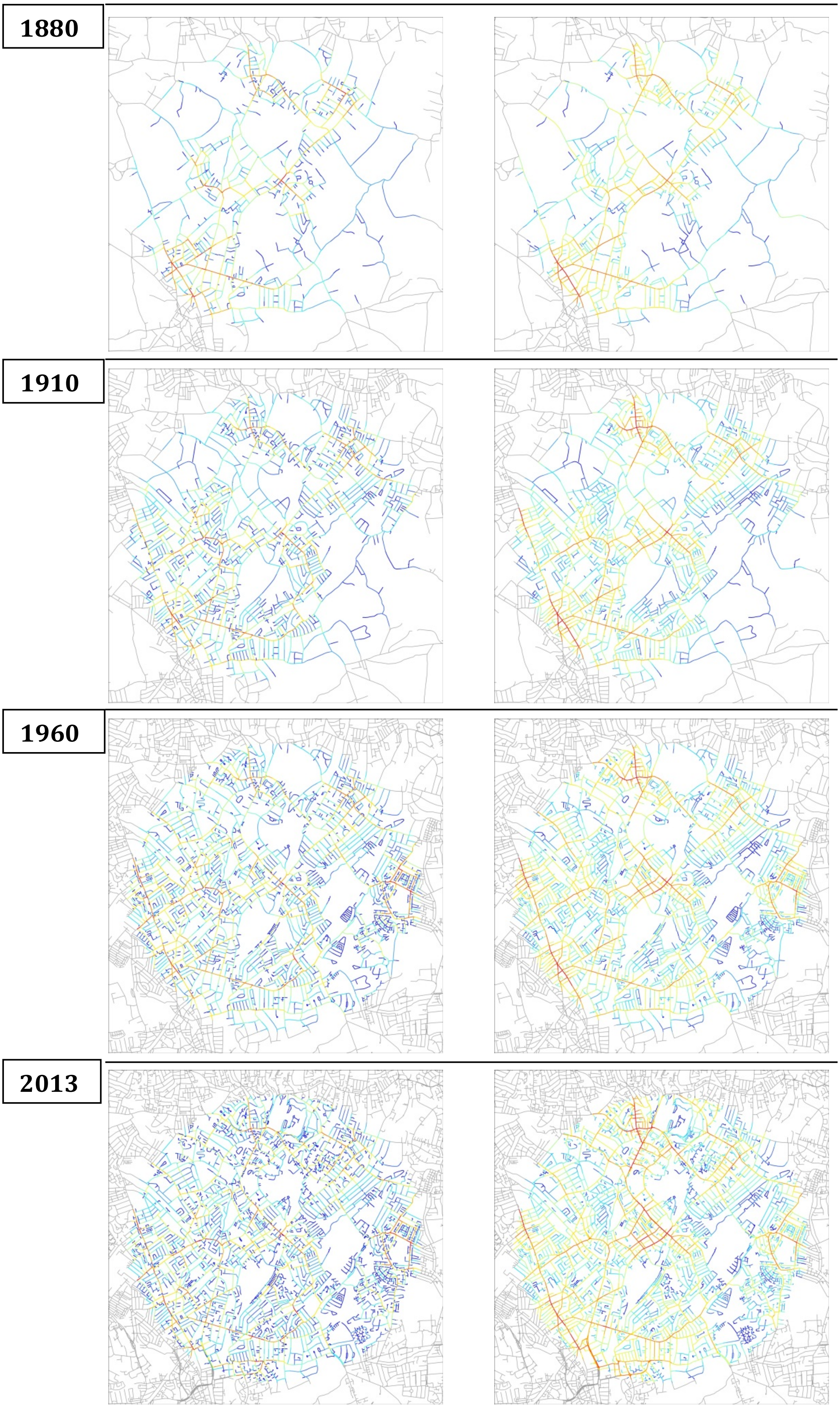


Figure 3a South Norwood choice (left) and integration (right) radius 800m.

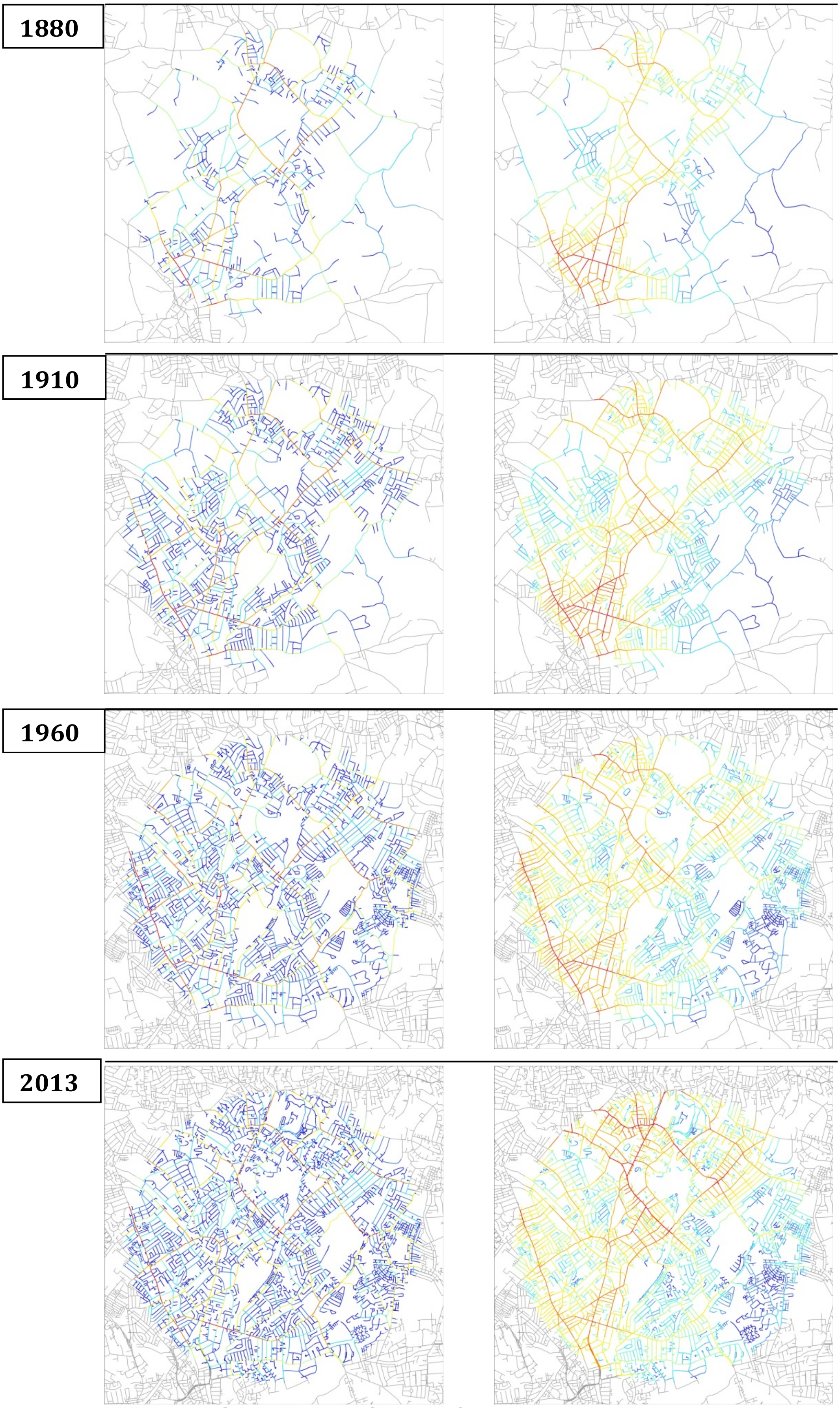


Figure 3b South Norwood Choice (left) and Integration (right) radius 3000m.

6.3.4 Surbiton

In Surbiton the total road network length increased from 134km to 372km over the period of analysis. This represents an increase of 8km of road network per square kilometre, reaching a total density of 12.5 kilometres of road network per square kilometre. In comparison to South Norwood, Surbiton can be said to have experienced a lesser rate of road network densification and overall to be less densely filled in by road network. Figure 4a shows the values for choice and integration at radius 800m in the Surbiton study area for the four time periods of 1880, 1910, 1965 and 2013 in sequential order (top to bottom); Figure 3b shows the same sequence for 3000 metres radius of analysis. From this sequence of maps the general trend that can be seen is, similarly to South Norwood, the reinforcing and growth of pre-existing centres, but there is a notable intervention of road network infrastructure that dramatically shifts the patterns of choice and integration at radius 3000m of analysis and to a lesser extent at radius 800m of analysis.

In 1880 there is a clearly defined central area of high integration at both 800m (fig. 4a) and 3000m (fig. 4b) radius of analysis, which focuses upon, and links Kingston, the large settlement in the north, with Surbiton and in the centre of the map and the adjacent north-south routes along Maple Road and Ewell Road. At 3000m radius the road running along the bend of the river is also significant. This orientation towards Kingston could be attributed to it locating itself at a crossing point of the river therefore acting as a gateway and attractor for centrality at 3000m scale of analysis. The spatial coincidence of high choice and integration at radius 800m is similar to that of South Norwood, also indicating locally coherent systems of to- and through- movement, although high integration network elements are more continuous than in South Norwood, indicating that it is a less fragmented area of spatially distinct settlements. At radius 3000m this is also the case, further indicating that the spatial system is orientated more towards a contiguous urban area.

During the transition from 1880 to 1910 the integration cores and routes of highest choice are built upon and extended in a similar manner to that experienced in South Norwood. This is indicative of densification around pre-existing centres and associated increased choice of the network elements that link between them. The one area that experiences significant change is located on the far eastern edge; at radius 800m of analysis a new centre can be seen to emerge amongst a build-up of dense street segments. As with the centre that emerges in the same period in South Norwood it does not feature prominently at 3000m of analysis, indicating it is a local spatial structure.

The spatial transformations that take place in the period 1910 to 1960 are far more dramatic and are the most significant of any time period in any of the four case studies. These are in relation to the construction of the curvi-linear A3 Kingston By-Pass running along the south eastern edge of the area. At radius 800m of analysis multiple local centres of integration appear in the southern, northern and eastern regions of the analysis area. In these areas there is also the development of high choice segments in the middle of the peaks of integration. The locations of particular note are in the southern and eastern areas around the Kingston By-Pass. In these locations, in contrast to previous periods, areas of high choice and integration are locating themselves on and around the large road infrastructure rather than around pre-existing town centres. The peak in choice and integration that appeared on the eastern edge at radius 800m of analysis in the previous period has now been incorporated into the 3000m scale of syntactic significance, linking to Kingston town centre in a similar way that the centre in South Norwood linked to Croydon over time. At radius 3000m of analysis the shift from 1910 to 1960 is most dramatic as the Kingston By-Pass becomes the strong integration core and roads linking to and across the by-pass become high choice. This is a decisive shift in the syntactic structure of the area, and also in comparison to South Norwood. Whilst in South Norwood over the whole time period of analysis and in Surbiton up until this point the increases in integration and choice have been focussed on and between pre-existing settlement centres this new type and scale of infrastructure changes this trajectory creating centrality around a wholly new spatial structure that does not reference any of the local historical spatial structure. It is interesting to note that by drawing integration and choice to the south of the area it enhances the choice and integration values in north-south direction between Kingston and the by-pass. This may in fact act to balance out the heavy northerly choice and integration bias, that the size and density of Kingston creates in the area.

From 1960 to 2013 the trajectory shifts in the spatial developments caused by the By-Pass persist but are changed in character. During this period the By-Pass gains elevated sections and become more un-linked from the local street network; more complex junctions are also introduced. There is also an extension to the By-Pass added that bends south on the southern edge of the area. At radius 800m the impact of these changes are actually to increase choice and integration values away from the By-Pass in the area between the By-Pass and Kingston; the changes to the By-Pass act to separate it from the local spatial structure. At 3000m radius of analysis the changes can be seen to have a negative effect on choice but positive on integration in the area in the south western corner. This is particularly interesting because in most periods increases in integration had an associated increase in choice. This indicates that depending on how large scale networks integrate with local grids there can be disproportionate changes between through and to movement potentials.

All study areas have unique spatial development trajectories and specific features, but also similarities. They all show the development of new syntactic centres away from the primary historic centres due to their later development and greater scope for densification; and the development of choice routes between these centres, creating links of through movement across the space. South Norwood’s peculiarity is in the strong divide between the north-western and south-eastern halves that persists through time. Surbiton’s unique feature is the Kingston By-Pass that creates a whole new type and scale of spatial structure, completely separate from the historical spatial structure. This change acts to create new types of centrality and movement potentials due to the infrastructure of the by-pass being designed solely for vehicular movement.

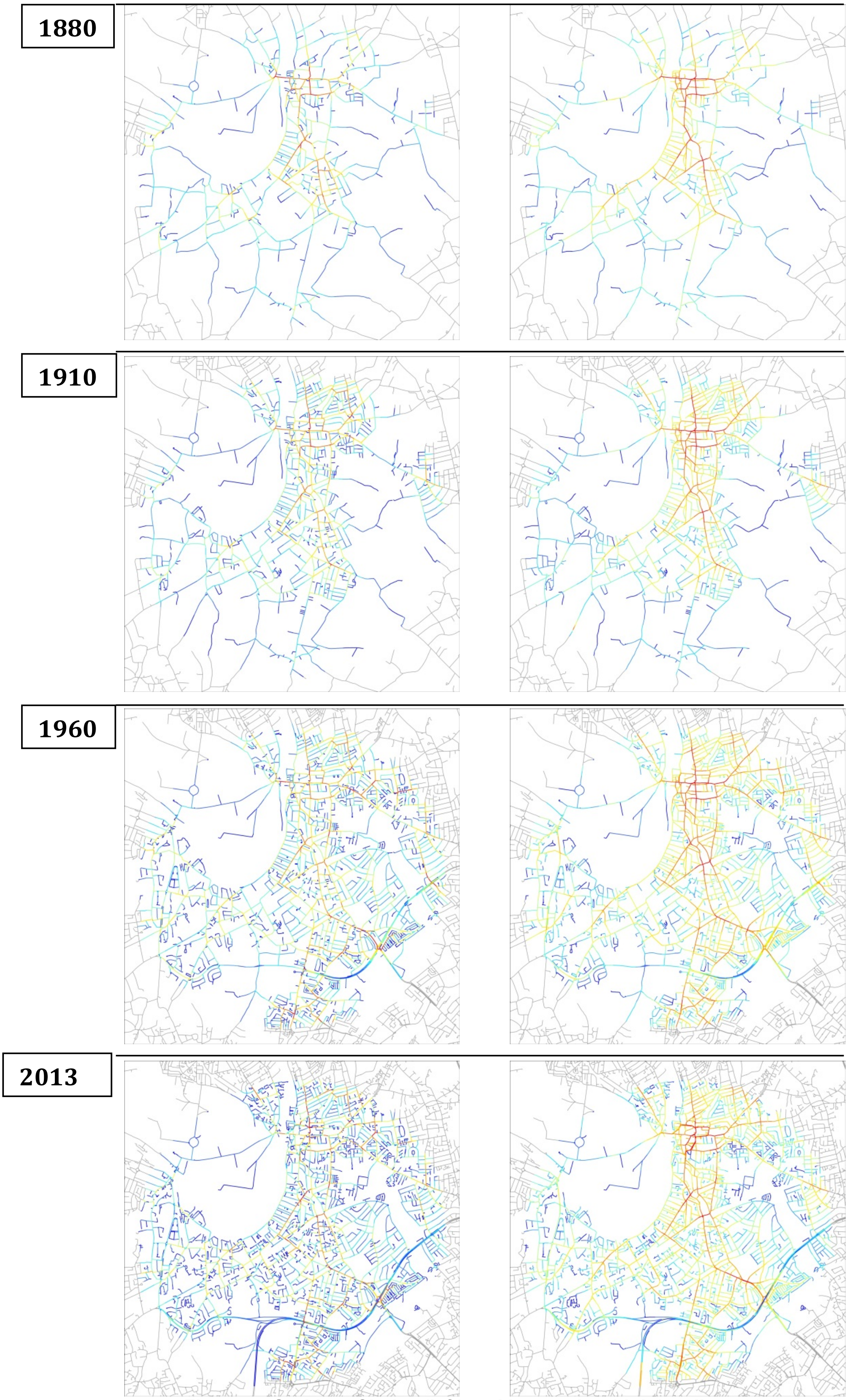


Figure 4a Surbiton Choice (left) and Integration (right) radius 800m.

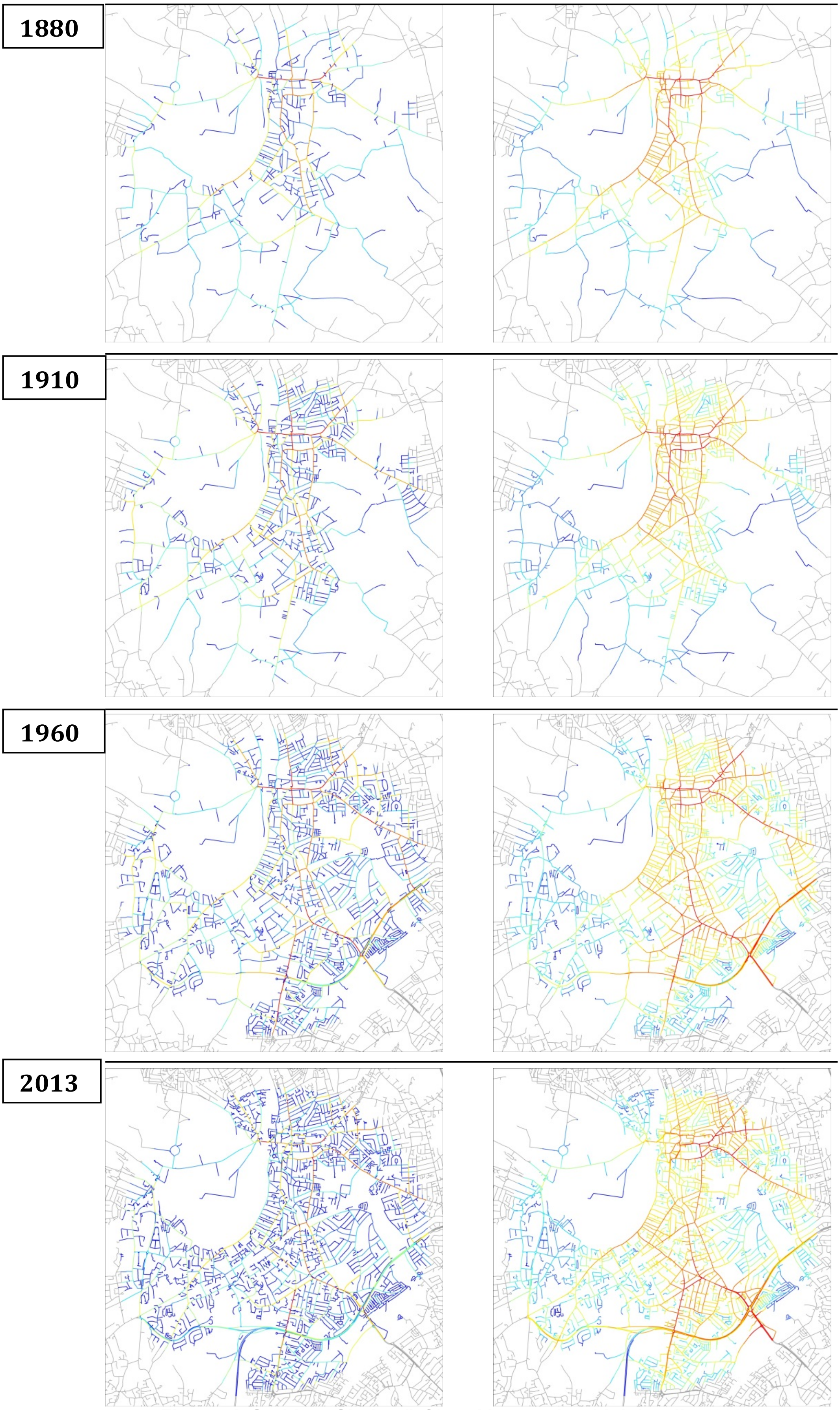


Figure 4b Surbiton Choice (left) and Integration (right) radius 3000m.

6.4 Surbiton and South Norwood Further Analysis

In this section two of the four cases, Surbiton and South Norwood, are subject to further statistical analysis. They were chosen due to their having a much greater network development than the other two cases and thus, an opportunity to understand the process of urbanisation in greater detail. Furthermore due to the limitation of the space syntax analysis software the issue of very low-density networks creates problems for the computation of choice and integration measures in studies of this type so Loughton and High Barnet would not have benefited from detailed statistical analysis of network change. This section deals with the change in the distribution and values of the choice and integration measures and then looks at the relationship between choice and integration through both visual and numerical analyses.

6.4.1 Choice and integration value distribution change

The previous descriptive evaluation of the space syntax network analysis of Surbiton and South Norwood showed that the evolution of the street network does not always follow a clear linear trajectory but happens unevenly and through differing mechanisms of small scale local development of grids and large scale network development. This takes the form of by-passes and motorways in close proximity to pre-existing dense network developments. Often this occurs with little interaction with local grids due to there being few connections between the differing scales of infrastructure.

To better understand the shifts through time of the syntactic properties of the network a numerical evaluation is necessary to analyse how the actual structure of the network values change over time. In figures 5 and 6 the values for choice and integration at radii 800m and 3000m are shown for Surbiton and South Norwood respectively. In these figures the frequency distributions of choice and integration values at the two radii are shown for all four time periods of analysis. These graphs allow for the structure of the value change in the networks to be easily visualised and compared across time, and to explore the observations already made from the visual interpretation of the maps statistically.

From looking at all the frequency distributions of the data the initial trend that can be observed is that the values for choice and integration change differently over time at both scales of analysis. Whilst integration values can be seen to increase, the values for choice do not increase in value to the same degree if at all. Instead the overall mass of higher values increases. Furthermore the skew in the distribution is opposite at 800m for choice and integration, indicating that at 800m radius of analysis many network elements are between many other network elements on the shortest angular path whilst there are comparatively fewer network elements that are angularly close to other network elements at 800m radius of analysis.

When integration is examined in isolation from choice, in both cases the change in values at 800m radius of analysis is minor, with a small increase in value indicated by the shifting centre of the peak of the distribution values to a higher level. The change that occurs over time is principally a gain in mass of network elements; as the network grows these elements attain similar levels of integration values over the 130-year time period. When the frequency distributions of integration at 3000m radius of analysis are examined a different picture emerges of the changing syntactic values through time. Whilst there is also the gain in mass of values indicated through the larger distribution curve, the values also increase sharply. This is the case for both Surbiton and South Norwood, but the manner of the increase is markedly different between the two cases. In South Norwood there is a gradual increase through steady, even increments in each period. In contrast Surbiton's syntactic values at 3000m radius of analysis do not follow a linear growth trajectory through time. Between 1880 and 1910 there are small changes to the values but it is smaller than the shift occurring in South Norwood in the same period. From 1910 to 19160 a dramatic uplift in values at 3000m radius of analysis occurs. This dramatic uplift coincides with both the introduction of the Kingston By-Pass as outlined in the previous section and the development of extensive local grids. This large-scale connectivity in conjunction with local small-scale grids acts to create a greater increase in the angular closeness of network elements at the 3000m radius of analysis. It is the interaction of the large-scale networks and the local grid intensification that can be seen in Surbiton between 1910 and 1960 that radically alters the structure and value of integration in the street network system. In the corresponding period in Surbiton there is also a large increase in the mass of values at 800m radius, highlighting the local grid intensification that occurs. The differences observed between the change in the values of integration in Surbiton and South Norwood reinforces the observations in the previous section of the incremental changes that occur in South Norwood over the whole time period of the study in comparison to Surbiton where there the greatest development of any period occurs between 1910 and 1960. Between 1960 and 2013 both South Norwood experience incremental increases in Integration at both 800m and 3000m radii of analysis.

The frequency distribution for choice shows a different aspect to the development of the syntactic structure to the street network over time. At 800m radius of analysis there is very little change apart from the increase in mass of values as the number of network elements increase, all attaining similar values to the previous periods. This is also the case at 3000m radius of analysis, except for the emergence of a secondary peak of values in 1960 and 2013. This peak of high values occurs in both instances, but is more pronounced in Surbiton than South Norwood. This peak in values is indicative of a secondary spatial system that attains very high through movement potentials at 3000m trip lengths developing in the period after 1910. In the case of Surbiton the secondary spatial system that facilitates high through movement potential is the Kingston By-Pass as it creates a highly linear route connecting many areas through an angularly simple network structure that is largely separated and spatially distinct from the pre-existing network structures. In the case of South Norwood the reasons for this secondary spatial structure emerging are less obvious, in that there is no large scale intervention like the Kingston By-Pass. The interventions that do occur are at the smaller scale and thus bring about a smaller secondary distribution of high choice values at 3000m scale of analysis. These small interventions are the development of greater traffic engineering around Croydon and introducing more complex traffic engineering on main arterial routes. Through these interventions the centrality of specific routes is increased through the numerous connections that lead to them.

From the analysis of the distribution of choice and integration values in Surbiton and South Norwood it can be seen that they experience differing trajectories in their network, and thus configurational development. South Norwood experiences a steady incremental increase in integration values across all time periods and a steady increase in the mass of choice values reflecting the greater number of network elements. On the other hand Surbiton experiences a disjointed development, where the introduction of the Kingston By-Pass brings about rapid local development in the period 1910 to 1960 brings about a sudden increase in integration values. The distinctive difference between integration and choice in regards to how they change over time is crucial in understanding city development processes. As shown in the previous chapter, sub-centres in the centre of London have markedly higher integration values at higher radii of analysis whilst the choice values remain similar across both inner and outer centres. In this analysis it can be seen that through time the values for choice remain largely stable apart from the emergence of a secondary distribution of higher values as a separate spatial system. Whilst choice remains stable, integration increases greatly. This increase relates to greater density of network elements whilst the stability of choice reflects the importance of pre-existing routes in defining development and the structure of the city developing around these primal routes of high through movement potential.

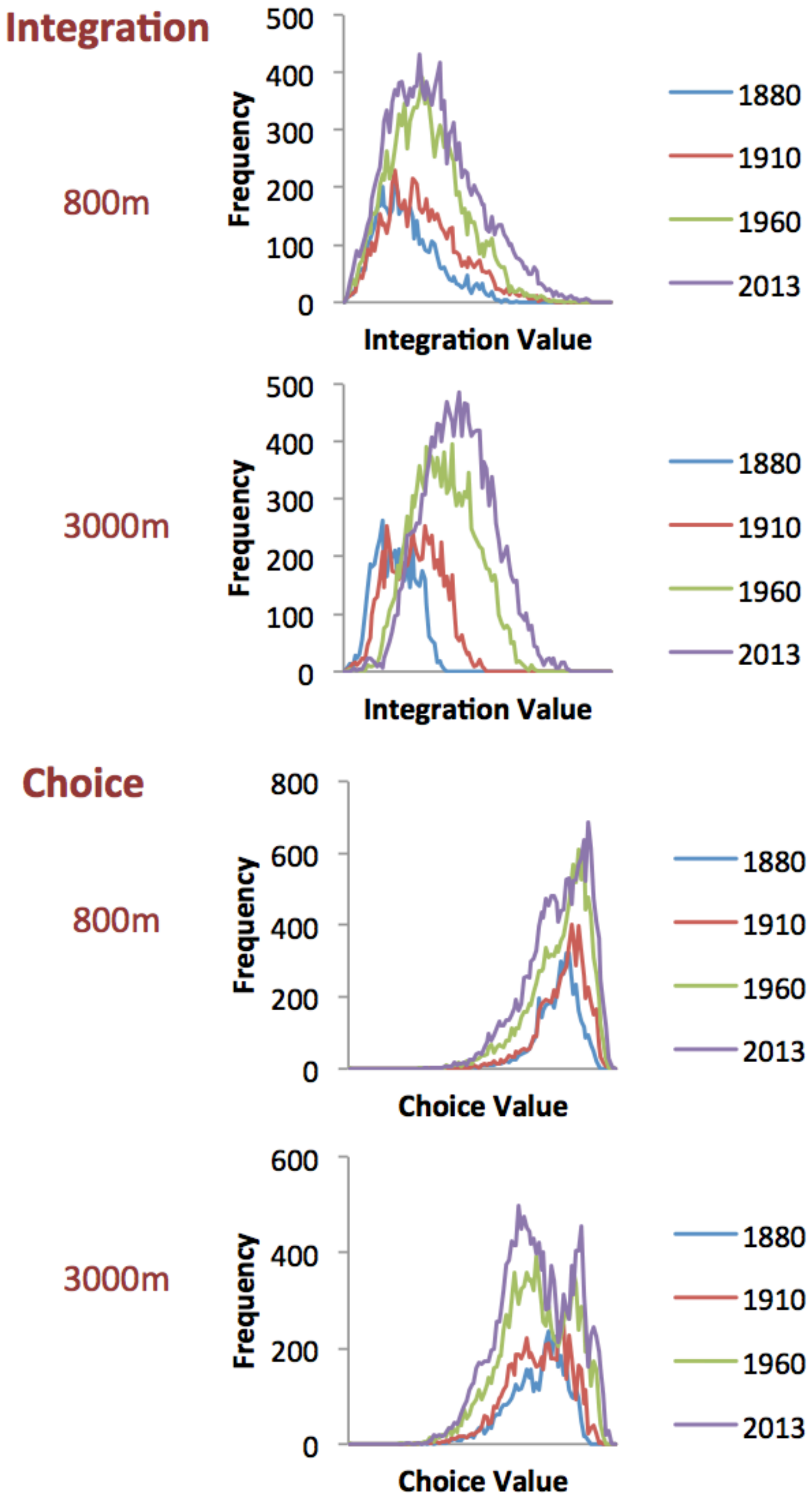


Figure 5 Surbiton frequency distributions for choice and integration at radii 800m and 3000m

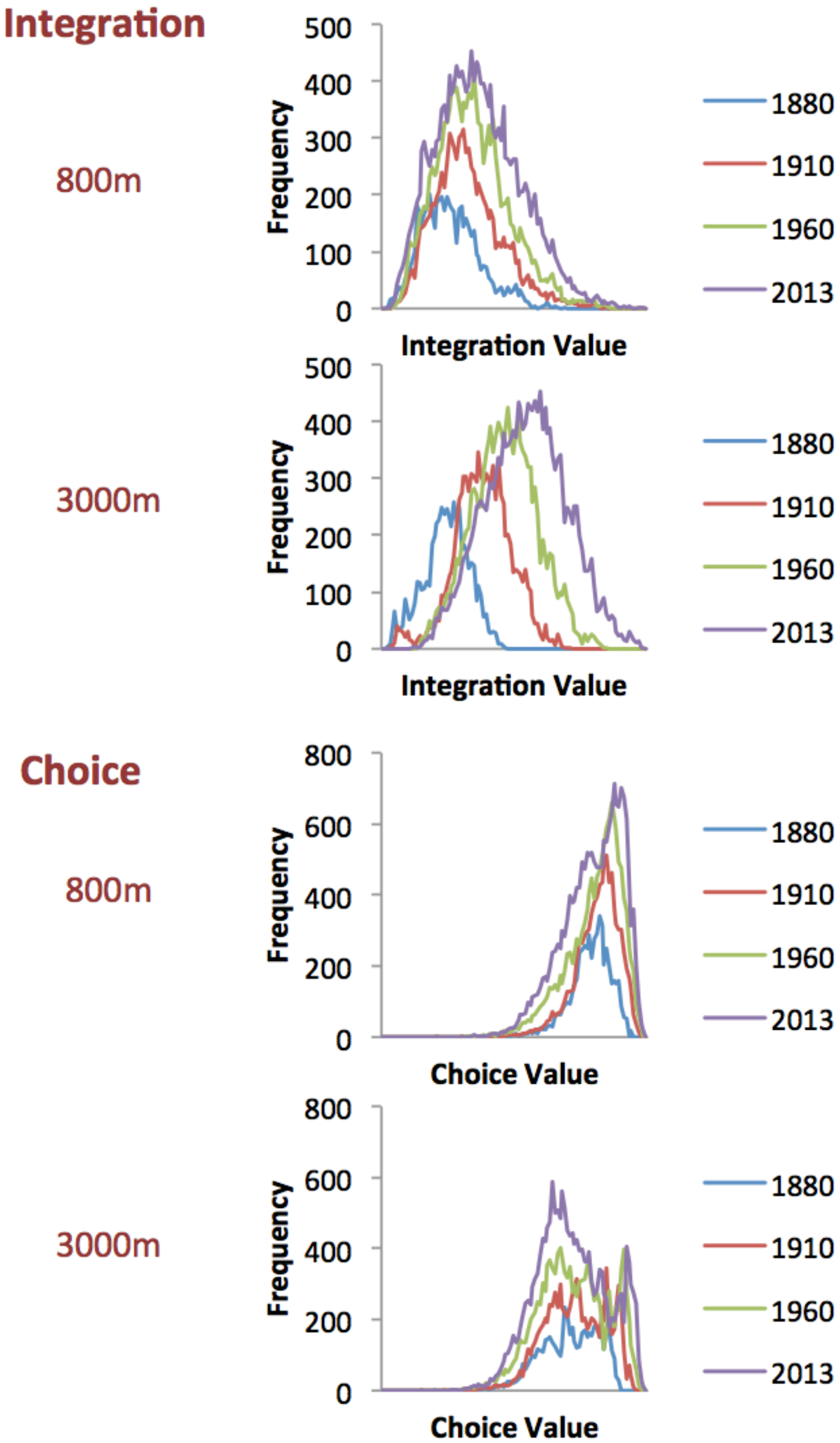


Figure 6 South Norwood frequency distributions for choice and integration at radii 800m and 3000m

6.4.2 Choice and Integration spatial co-evolution

Whilst the descriptive and numerical analysis of the changing spatial properties of South Norwood and Surbiton serve to illustrate their overall spatial and configurational development, a more in-depth analysis of what the choice and integration values actually show is necessary. In the description of the primary space syntax results it was suggested that choice and integration follow each other in the locations where the peak values develop, but integration reveals the areas of road network densification and choice shows the primary linkages between these integration cores; there is only an overlap of the highest values in a small number of locations and this relationship differs between scales.

It is proposed that where the overlap between the highest values of choice and integration occur can be characterised as locations of high to and through movement potentials, and what can be termed co-presence. Whilst co-presence normally refers to spatial proximity between individuals in space the term is used here in a spatial sense to describe locations where the network is structured in such a way as to bring together through and to-movement potentials, and bring about the possibility for co-presence to occur. It is proposed that in the locations where there is the greatest overlap between the highest values for choice and integration there is the highest likelihood of the occurrence of activities associated with town centres, as there will be people moving through them for different purposes supporting a variety of land uses

In order to explore the relationship between choice and integration pearson coefficients of correlation were calculated for all time period in both case study areas for 800m, 1600m, 2000m and 3000m radii of analysis between all integration and choice values. The results are shown in table 1; the correlation coefficient values are coloured from high (red) to low (green). From this figure it can be seen that across all time periods and case studies the strongest correlation that exists is between choice and integration at 800m radius of analysis. The correlation between choice and integration at radius 800m is always greater than 0.5 indicating a significant relationship; whereas at greater radii it is statistically insignificant in the majority of cases.

The most prominent trend in the data is, that as the choice and integration radius of comparison is increased the statistical relationship between the two spatial measures decreases. This result suggests that at the small scale the structure of space acts to tie together the through and to movement in the same network locations but as the scale of relation is increased there is a divergence between the network elements of the highest choice and integration. The divergence is suggestive of a scaled urban structure that knits together small network structures with coincident through and to movement but at the largest scale it does not act to internally cohere them, but links them to other parts of the network. The result of this is that at the largest scale they are serving two separate spatial purposes of either generating centres or linking them; whilst at the local scale they serve both spatial purposes.

Over time the data shows a trend of weakening correlations across all scale of comparison. This trend towards wakening correlation is suggested to signify a system of spatial specialisation occurring whereby as the network develops segments attach preferentially to the elements of highest choice without altering their spatial structure; this is also likely due to the importance of these network structures precluding significant alterations. This will create clusters that are proximate but do not overlap with elements of highest choice, thereby maximising the utility of locating near to high through movement potentials without having a negative effect on the spatial structure that they are trying to exploit. This relates to the previous chapter’s whole London analysis in that it again shows how at the larger scales of analysis there is a divergence in the type of centrality that choice and integration measure.

South Norwood

1880	i800	i1600	i2000	i3000
ch800	0.67	0.48	0.41	0.35
ch1600	0.61	0.51	0.45	0.39
ch2000	0.57	0.49	0.44	0.38
ch3000	0.49	0.39	0.35	0.33
1910	i800	i1600	i2000	i3000
ch800	0.61	0.41	0.35	0.28
ch1600	0.52	0.45	0.41	0.33
ch2000	0.48	0.44	0.40	0.33
ch3000	0.42	0.40	0.37	0.32
1960	i800	i1600	i2000	i3000
ch800	0.62	0.44	0.38	0.31
ch1600	0.55	0.48	0.43	0.35
ch2000	0.50	0.46	0.42	0.35
ch3000	0.43	0.41	0.38	0.32
2013	i800	i1600	i2000	i3000
ch800	0.57	0.40	0.35	0.28
ch1600	0.52	0.42	0.37	0.30
ch2000	0.48	0.41	0.36	0.30
ch3000	0.41	0.36	0.33	0.28

Surbiton

1880	i800	i1600	i2000	i3000
ch800	0.63	0.50	0.45	0.39
ch1600	0.54	0.49	0.44	0.38
ch2000	0.50	0.46	0.42	0.37
ch3000	0.42	0.37	0.35	0.33
1910	i800	i1600	i2000	i3000
ch800	0.63	0.49	0.45	0.38
ch1600	0.54	0.45	0.41	0.35
ch2000	0.48	0.41	0.38	0.33
ch3000	0.38	0.32	0.30	0.29
1960	i800	i1600	i2000	i3000
ch800	0.62	0.46	0.41	0.32
ch1600	0.53	0.49	0.44	0.36
ch2000	0.47	0.47	0.43	0.36
ch3000	0.38	0.40	0.39	0.35
2013	i800	i1600	i2000	i3000
ch800	0.57	0.44	0.40	0.34
ch1600	0.49	0.44	0.41	0.35
ch2000	0.44	0.42	0.39	0.35
ch3000	0.35	0.35	0.34	0.33

Table 1 Table of Pearson correlation coefficients for all time periods in South Norwood and Surbiton

In order to investigate the spatial relationship between the locations where there is the greatest overlap between high choice and high integration network elements the top 10% of values for choice and integration at radius 3000m were mapped and matched against one another. This was carried out in order to find where they were coincident. Radius 3000m was chosen for this process since this exhibited the weakest correlation between the values and would therefore show the statistical outliers of the correlation and potentially significant locations within the network.

Figure 7 shows a time series of co-presence maps for South Norwood and Surbiton. This series of maps show the network elements that are in the top 10% of values for choice and integration at 3000m radius of analysis in 1880, 1910, 1960 and 2013; the boundaries of the town centres as defined today are overlaid in blue. In the 1880 South Norwood case study area the co-presence lines are leading into the town centre of Croydon and Crystal palace, with a small presence on the cross roads in the centre of South Norwood. Thornton Heath on the western edge and Penge in the north-east do not have any lines of co-presence. In 1910 the lines of co-presence have extended to Thornton Heath and a line extends from the centre of Penge. Overall the lines of co-presence have extended further in comparison to the previous period. By 1960 the lines of co-presence have begun to join up across the area, linking South Norwood and Crystal Palace. Thornton Heath and Croydon are now situated on a continuous line of co-presence. In the final period of 2013 the lines of co-presence form a continuous network linking all of the town centres across the area; as with the space syntax analysis above, the south-eastern half of the study area is segregated and does not form part of this continuous network of co-presence. Reinforcing the notion of a spatial divide within the study area.

In Surbiton the lines of co-presence in 1880 intersect the town centres of Kingston in the north and Surbiton in the centre of the study area. In 1910 the lines of co-presence can be seen to retreat slightly to focus more strongly around Kingston whilst still maintaining a presence in South Norwood. By 1960 the lines of co-presence have been radically altered in line with the general space syntax analysis. The introduction of the Kingston By-Pass in the south of the study area has crated many lines of co-presence around this new network structure, but it also acts to increase the lines of co-presence that run north towards Kingston. A line of co-presence also now intersects the town centre of Tolworth in the south. The overall network of co-presence is actually split between a southern and northern continuous network focussed around the By-Pass and Kingston respectively. By 2013 the lines of co-presence have linked up to form a continuous network that connects in a north south direction along one route in the centre of the study area. This network still does not incorporate the town centre of Molesly Lock on the western edge of the study area.

The evolution of co-presence in the South Norwood area can be characterised as growing in a continuous pattern to link between the town centres of the area. There are no major shifts in the pattern of the growth of lines of co-presence. In comparison, Surbiton experiences a radical re-configuration of the lines of co-presence with the introduction of the By-Pass. Importantly the By-Pass as a location of co-presence is quite different since it is purely for vehicular movement. This means that the type of co-presence that is theorised acts to create live centres cannot operate here because people cannot utilise the network on-foot and the associated potentials of the movement economy cannot be exploited.

Figure 7 Network co-presence in South Norwood (left) and Surbiton (right); contemporary town centres overlaid in blue.

6.5 Summary

This chapter has presented the detailed historical account of the morphological evolution of four peri-urban areas over a 130-year period, and subsequently examined in two of the case studies the relationship between choice and integration, both numerically and visually. With the exception of South Norwood, it can be seen that the period between 1910 and 1960 represents the most significant period of urban development in the case studies. During this period the most extensive grid expansion and densification took place. South Norwood did not experience the same sudden growth in the period 1910 to 1960, but gradually grew at a steady rate over the whole 130-year period. Apart from the development of more local grid systems the other striking feature that can be seen in Surbiton in the 1910-1960 period, and in Loughton in the 1960-2013 period, is the development of large city-scale road network infrastructures. The M11 in the Loughton study area, and the Kingston By-Pass in the Surbiton study area represent significant departures from the growth trajectory and pre-existing street network structures. These network developments are shown to have had distinct configurational impacts, either very little or significant, depending on how the infrastructure interacted with the pre-existing street networks. The differences in the level of configurational interaction that new, large scale road infrastructures have with the local pre-existing street network is important to understanding how the process of city growth either bypasses, or enmeshes local historic street networks in city scale networks. This has implications for the spatial relationships of local centres with the city as a whole, and the types and levels of movement that will occur in an area due to the movement that is generated by the new configurations of the street network. Furthermore, whilst the historic street network may have persisted the new network configurations may greatly alter the structuring of movement within those historic networks

The further statistical analysis of South Norwood and Surbiton showed that they exhibited different growth trajectories, reflecting the non-linearity of the street network growth processes that they experienced over the time period of the study. This was shown in the changing structure of the values for integration at both the local and sub-regional scale. Choice was shown to change in distributional structure through time, but the values did not. Importantly in the last two periods a second distribution of high choice values at the 3000m radius of analysis emerged, this secondary distribution is indicative of a separate system of connectivity being present at this scale that is not directly linked in configurational terms to the local grid system. This relates to the higher-level system of choice, as observed in the previous chapter at the highest radii of analysis of 10,000m emerging as the city develops through time into one coherent, interwoven network structure. This is linked to the scale of the planning regimes of the city expanding to encompass the totality of the urban area rather then smaller sub-regions.

To further understand the spatial relationship between choice and integration the co-presence analysis was conducted to understand the spatial interaction of the two network properties over time. It was shown that the development of the network acts through time as to connect the locations where high choice and integration overlap, creating a network of the highest choice and integration values connecting across most of the space. This was shown to also be differential in that some areas, particularly in South Norwood where the eastern portion of the study area never become part of this dual high centrality network, and therefore is spatially segregated in terms of the network potential to generate through and to-movement in the same locations. This could preclude it from the potential benefits of having flows of movement operating across a range of scales, that is suggested are necessary for the urban movement economy to take root (Hillier, 1996).

From the analysis it is clear that while there are similarities across all the examined areas, there are local peculiarities and variation within the spaces of the case study areas in their morphological development through time. In order to better understand this process the next chapter looks at the built form development in South Norwood and Surbiton, to assess the architectural development of open spaces in relation to the network development, and to tease out the relationships between network and built form transformation over time.

Key Findings:

- The period between 1910 and 1960 is the most significant stage of street network development across the four case studies with the exception of South Norwood that grew more gradually across the timer period of analysis.
- Within the study areas of Loughton and Surbiton large-scale road infrastructure developments took place that did not reference historic local network configurations.
- A secondary distribution in the values for choice was shown to emerge in the later periods at 3000m radius of analysis.

- The co-presence properties of the network explored through the spatial overlap of the highest choice and integration values was shown radiate from the local centres, expanding over time until all the centres are enmeshed in a continuous high co-presence network.
- South Norwood was found to have a strong divide within the study area, expressed across scales of choice and integration analysis, as well as the co-presence analysis.

7 Analysis of the Historical Evolution of Built Forms

7.1 Introduction

The previous two chapters of analysis have focused firstly on the connectivity and general structural properties of the contemporary network in the context of the whole London street network, and secondly on the historical configurational development of the network as exposed with space syntax analysis. This chapter moves beyond solely examining the changing structure of the street network that connects space together and brings in the architectural forms that populate the accessible spaces afforded by the street networks development and expansion over time.

This chapter's analysis teases out the potential of the street network to shape the pattern of flows in particular spaces and studies how this has changed over time. Unusually for space syntax studies of this type, the analysis extends beyond the network to the building level to allow an understanding of how the system of streets and buildings in the urban environment develop in concert. The proposition is that the two form together a related system of functionally integrated architectural forms allowing both movement and stationary activities such as domestic, social and employment related activities. The hypothesis is that such activities take place in locations that correspond to the structure of the street network as according to measures of local and global accessibility interrelatedness as laid out in the theory of the movement economy (Hillier, 1996).

This chapter presents the results of the application of a novel methodology that is employed to generate analytically useful geographic data in vector format for individual building footprints from historic raster mapping. The resulting analysis of buildings in Surbiton and South Norwood examines the changing spatial patterns of development and compositional characteristics that emerge over time. The understanding generated from the analysis of the changing building forms and the previously presented network analysis aims to measure the interdependencies between the spatial forms of new infrastructural developments and the buildings of the everyday. Furthermore an understanding of the utility of city space from detailed land use reconstruction highlights the changing potentials for social encounter and exchange in spaces beyond the street.

7.2 Methodology

As laid out in the chapter describing Data Appraisal and Methodology, one of the principal challenges that are encountered during historical geographic research using cartographic sources is the type of data that are available. The main problem is that it is in a format that has very little analytical utility beyond display. The highest resolution contemporary data on the other hand is always available as vector format data that has specific geometries for every object in the map that can be spatially analysed, compared and combined in new way to understand spatial relationships between different geographically related objects that populate a given geographic area.

To be able to carry out an analysis of the historical development of the buildings in the case studies it is necessary to employ a methodology that allows for the extraction of vector data objects form the historic mapping. A software package called RxSpotlight Pro produced by Rasterx S.A. is a software tool designed for the automated digitization of engineering drawings, but with the ability to handle geographically located data and output GIS data files. An example of the output generated by the automated vectorisation process is show in Figure 1. The vectorised files then have to be processed manually to select the desired building features and cleaned to correct any errors in the digitisation that resulted from poor resolution original scans of the historical mapping, or unclear cartography in the original maps that could not be read by the vectorisation software. Due to these limiting factor the area that the process was completed for across the three historic time periods was an area of 12.5km^2 around each of the town centres of Surbiton and South Norwood, totalling 25km^2. For the contemporary period the data that is used for building footprints is a subset of the Ordnance Survey Master Map Topography GIS dataset that includes all buildings and built structures.

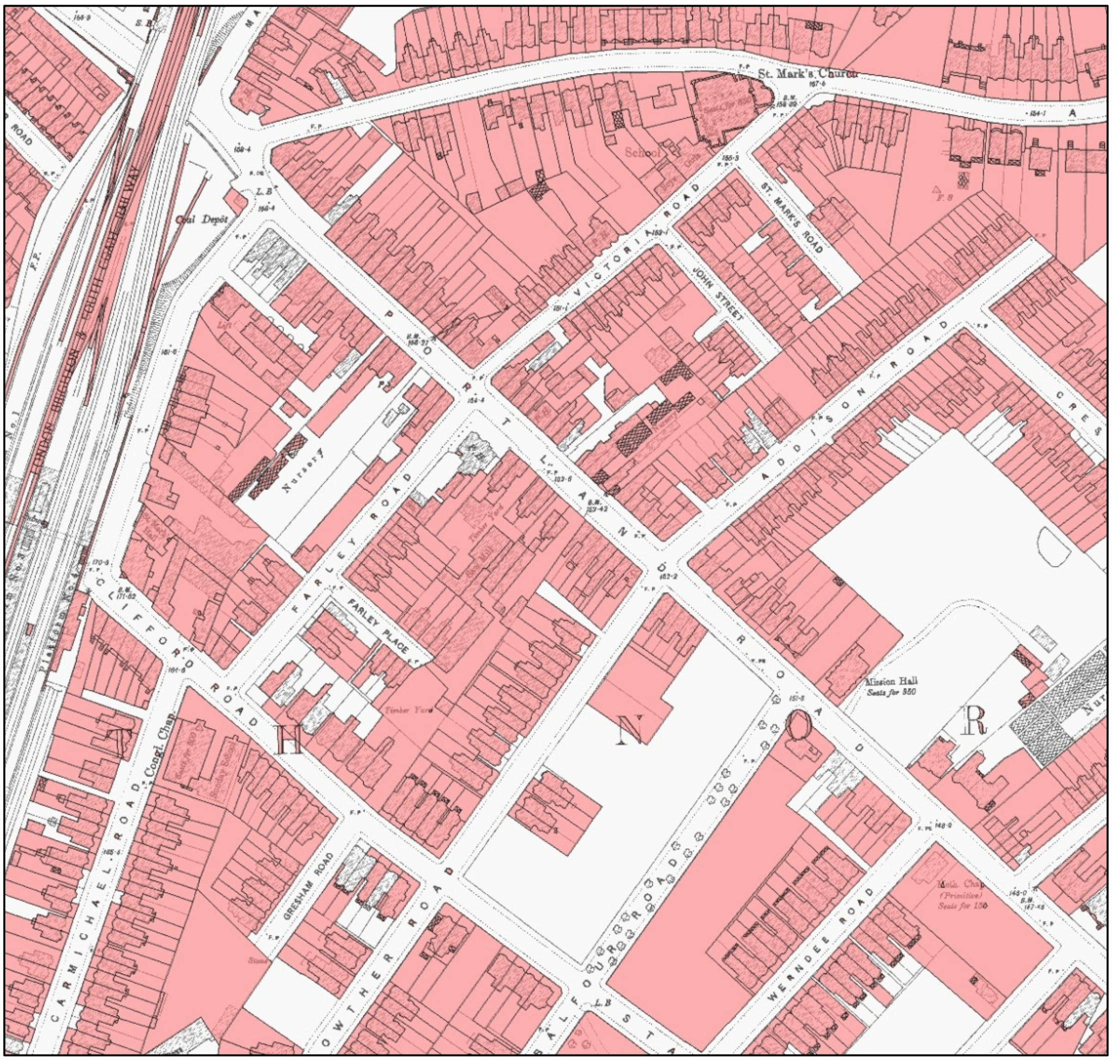


Figure 1 Example of automated vectorisation output from RxSpotlight Pro software. Vector data in red overlaid on raster source map.

7.3 Historical Building Analysis

In figure 2 the time series of the building footprint records for Surbiton (top) and South Norwood (bottom) are shown. From a simple reading of the maps it is clear that there has been near complete urbanisation if the spatial continuity of built forms is seen as a measure of this. It shows that over the period of analysis South Norwood developed from having principally open space to being nearly completely built-up. The situation in Surbiton is similar but the area around Hampton Court Palace is still not built upon due to its protected nature. Observing the patterns of the building development in both cases it can be seen that there is a spatial pattern to the growth processes. In Surbiton in 1800 the most built up areas extend from the north of the study area around the centre of Kingston southwards to Surbiton and then dissipates. By 1910 this southerly extension from Kingston has grown to make a larger continuous built up area, in 1960 the majority of the area has been built upon and in 2013 this is consolidated with near complete built up across the study area. In South Norwood it is apparent that a similar pattern of build up over time takes place, in the earliest period the built-up area extends from the south west, around Croydon to the north east of the study area, around Crystal Palace. In 1910, similarly to Surbiton the corridor of built up area has expanded, in 1960 the majority of the area is built upon and in 2013 the entirety of the area in built up.

This pattern of building development suggests that patterns of urban expansion that have been observed at the city scale, such as the emergence of conurbations creating city-regions also occurs at far smaller scales of urban development. In both cases it can be seen that the earliest expansion is brought about by connecting and developing corridors of built up areas between local centres. In the later periods when the most rapid urban expansion takes place the process is less nuanced and the growth of the built-up area occupies all the space that is available rather then building up gradually, connecting local centres. The secondary stage of expansion that almost completely fills both study areas from 1910 onwards suggests that in this stage rather than local growth occurring it is growth at the city scale and the areas are becoming fully enmeshed in the continuous urban fabric of the London metropolis.

Graphs 1 and 2 show the changing network length in comparison to built area across all time periods in Surbiton and South Norwood. In these graphs the network length is doubled in order to represent the fact that buildings can be built on both sides of a length of road. The land area covered by buildings increased from 200,000m^2 to

1,628,000m^2 in Surbiton, and from 250,000m^2 to 2,342,000m^2 in South Norwood over the time period of study. This represents an increase of 814% and 936% in the built area of Surbiton and South Norwood respectively. In comparison to the network development over the same period in the two cases in terms of length and area built structures develop at a far greater pace than the network. Over the same time period the network grows by approximately 275% in both cases. This indicates that at this simplistic descriptive level the relationship that exists between built area and network length over time is not linear and that as the process of urbanisation takes place and built structures grow at a greater rate than the network. The ratio of built area to network length in Surbiton rises from 1.5m^2 of built area per metre of road network to 4.5m^2 of built area per metre of road network between 1880 and 2013. In South Norwood over the same time period the ratio increase from 1.6m^2 of built area per metre of road network to 5.4m^2 of built area per metre of road network. This shows that the load of built mass on the network increases by 3x over the period of study, and in South Norwood there is an increase of 3.7x.

This mismatch between built structures and network growth indicates that the network development, in a sense foreshadows building development, in that capacity is present in the network configuration that is only later exploited by buildings that populate the street network. The ability of the network to absorb future urban growth is vital in an ever changing and expanding urban region so that the skeletal structure of the city is capable of providing routes to greater urbanisation.

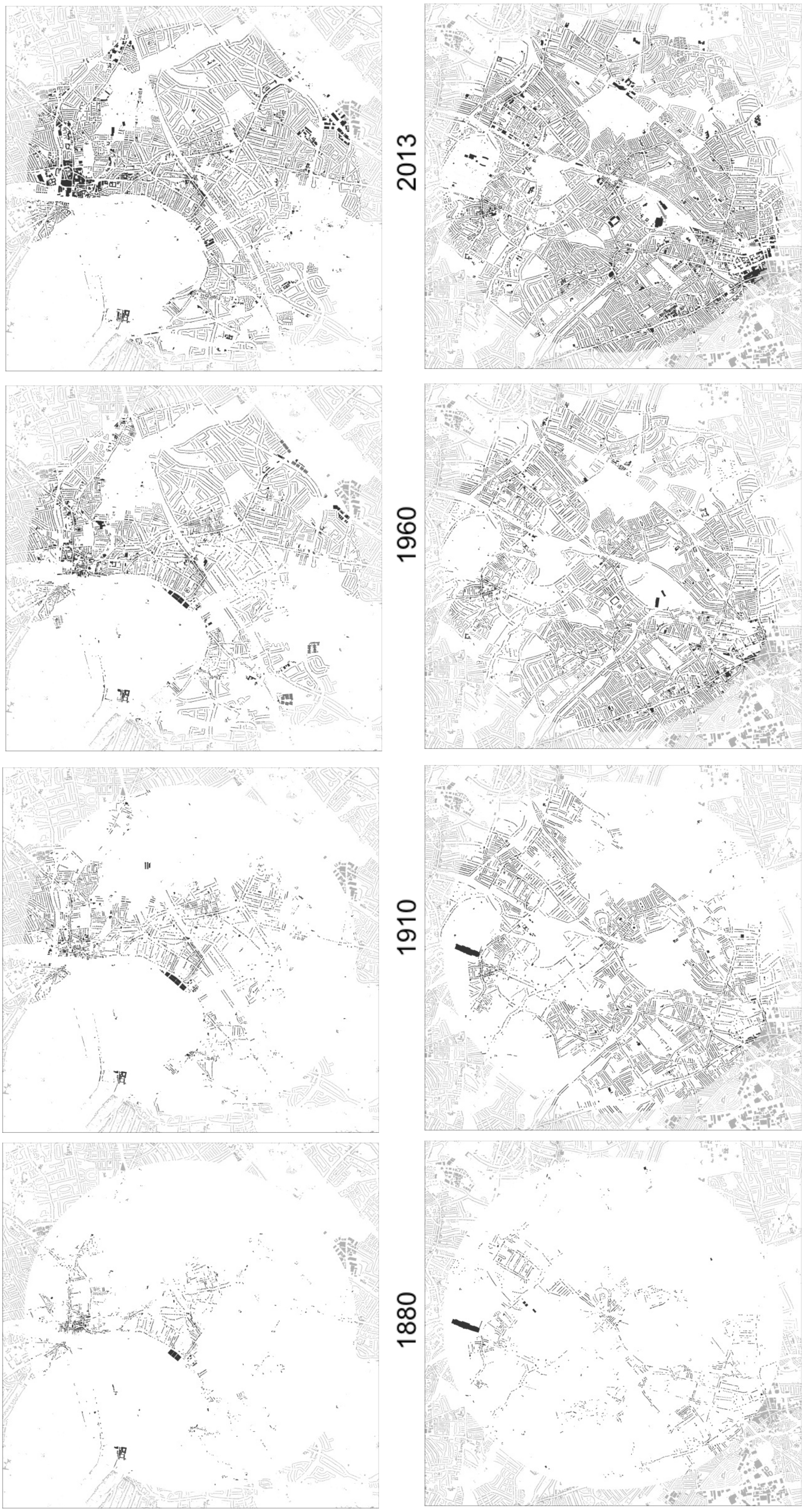
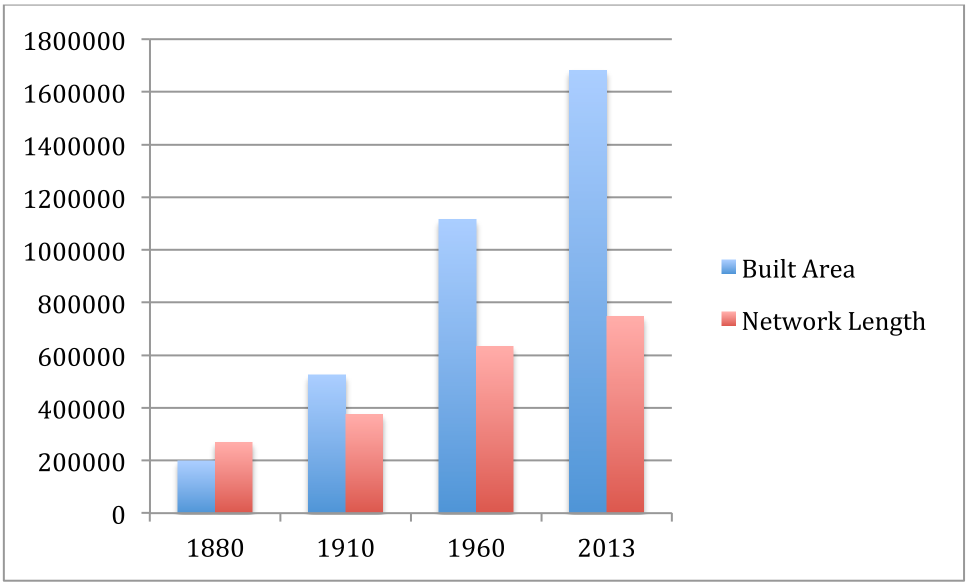
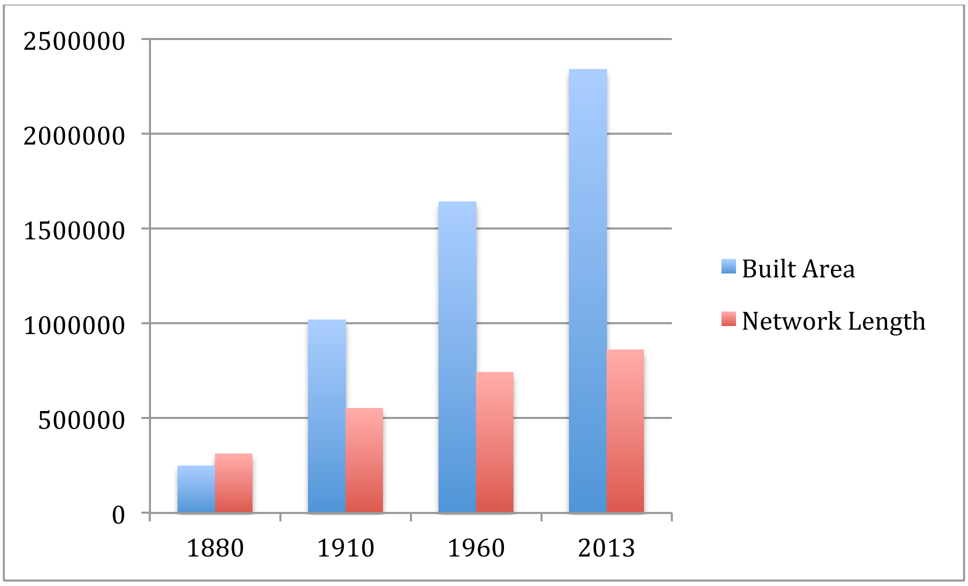


Figure 2 Reconstructed historic building footprints for Surbiton (top) and South Norwood (bottom). The contemporary building footprints outside the study areas are shown throughout for context.



Graph 1 Comparison of Surbiton street network length (m) change in relation to built area (m^2) change



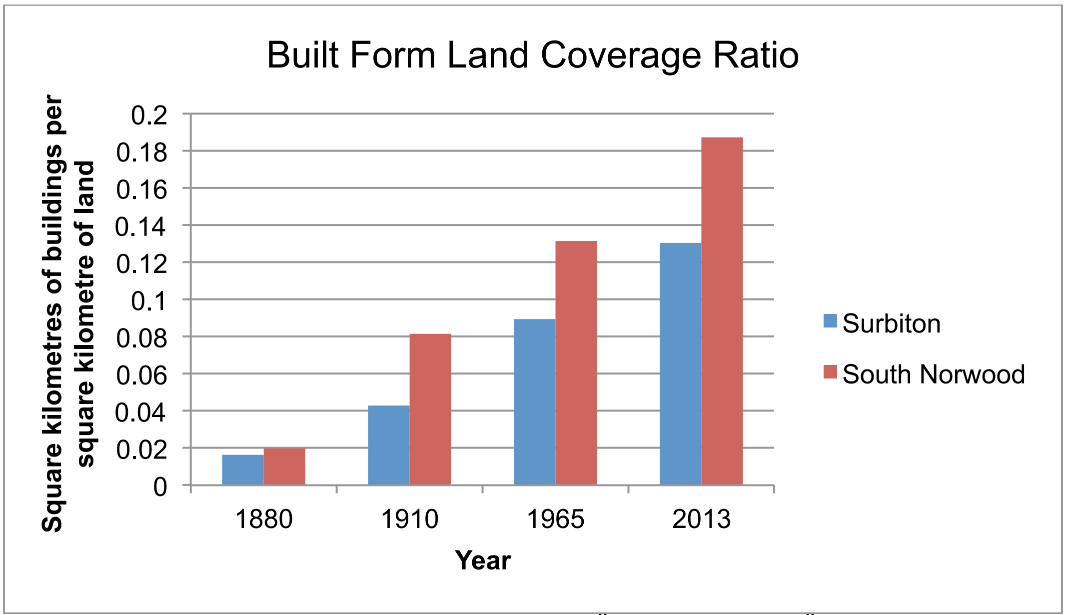
Graph 2 Comparison of South Norwood street network length (m) change in relation to built area (m^2) change

7.3.1 General statistical description

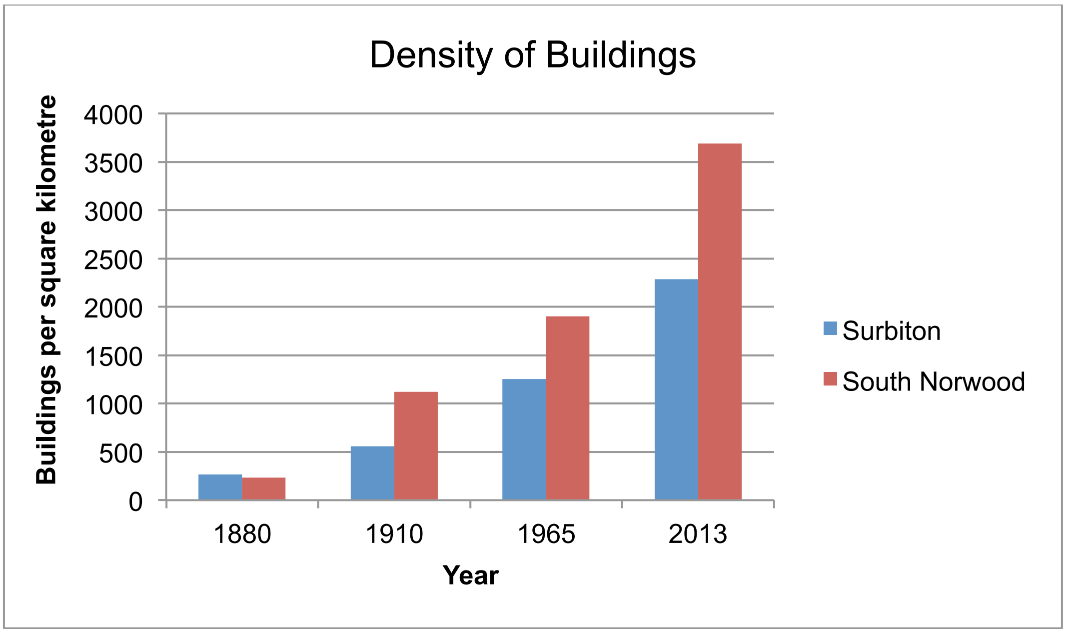
In graphs 3 to 5 the basic properties in the development of built structures over time are shown. In graph 3 the ratio of built area to land area within the analysis boundary is shown for both Surbiton and South Norwood. From this graph it can be seen that South Norwood consistently has a higher ratio of buildings to land area, South Norwood experiences a nearly ten-fold increase in the ratio over the period of the study. In graph 4 the count of individual built structures per square kilometre of the analysis area is shown, here the dramatic increase is also illustrated with Surbiton increasing from 266 to 2,284 and South Norwood increasing from 235 to 3,691. These huge increases in the built-up area and building counts further indicate that the non-linear relationship between network length and buildings has another component that is not captured in these numbers.

When the size of the buildings is taken into account the reasons for this become clear. In graph 5 the average building sizes fro both case studies over the period of analysis is shown, here it can be clearly seen that over time the average size of the building footprints decreases steadily with the exception of the Surbiton in the period from 1880 to 1910 when there is an increase. In Surbiton the average building size increases from 61m^2 to 76m^2 between 1880 and 1910, and then decreases to 57m2 by 2013. In south Norwood the average building size decreases across the whole time period from a peak of 84m^2 in 1880 to 50m^2 in 2013.

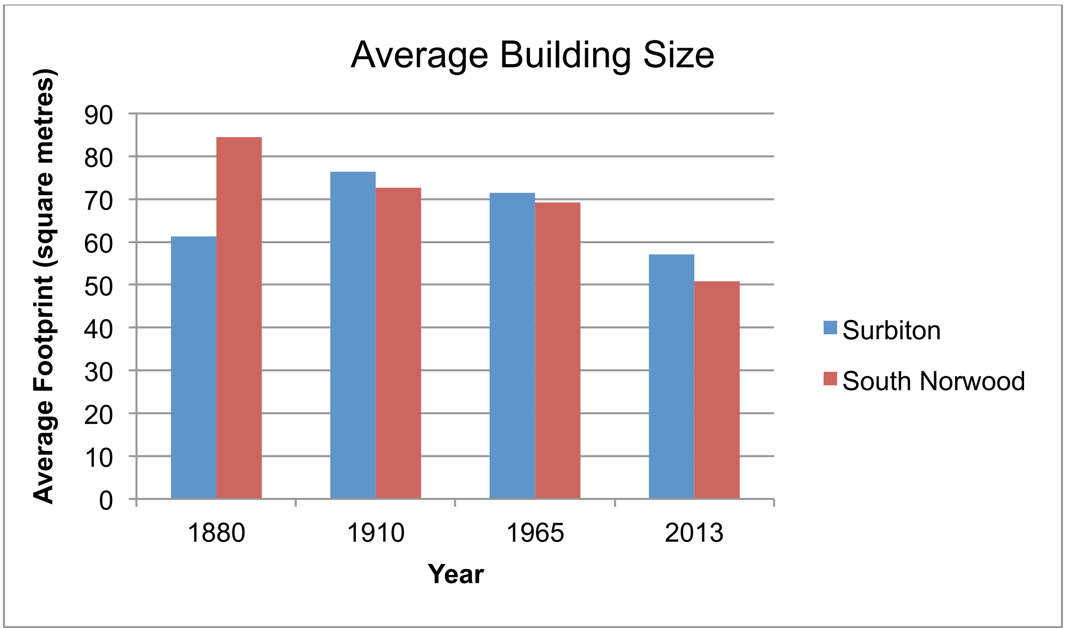
The changing size in the buildings partially accounts from the non-linear relationship that is observed between network length and built area. As the area is urbanised and the street network grows, the built landscape also changes in character, the buildings' spatial distribution becomes more dense as shown in graph 3 but also the buildings become smaller, or at least partially constituted of more smaller buildings, allowing for more built area to be accommodated on a network that does not grow at the same rate. From this it can be seen that over time built landscape changes to accommodate greater density with the development of smaller and more densely packed buildings that are more efficient at creating areas of greater density on a limited network space. This illustrates succinctly the city forming process, as an area transitions from semi-rural to urban the buildings condense into smaller more densely packed areas that allow the city to grow, whilst minimising expansion over a larger area that would create inefficiencies in distance and therefore accessibility to different parts of the urban area. Maintaining efficiencies of movement between locations and the associated exchanges that occur in the city is one of the defining characteristics of the success of cities as self-organising complex systems.



Graph 3 Changing built land coverage over time, km^2 buildings per km^2 land area



Graph 4 Changing density of buildings. Count of buildings per km^2



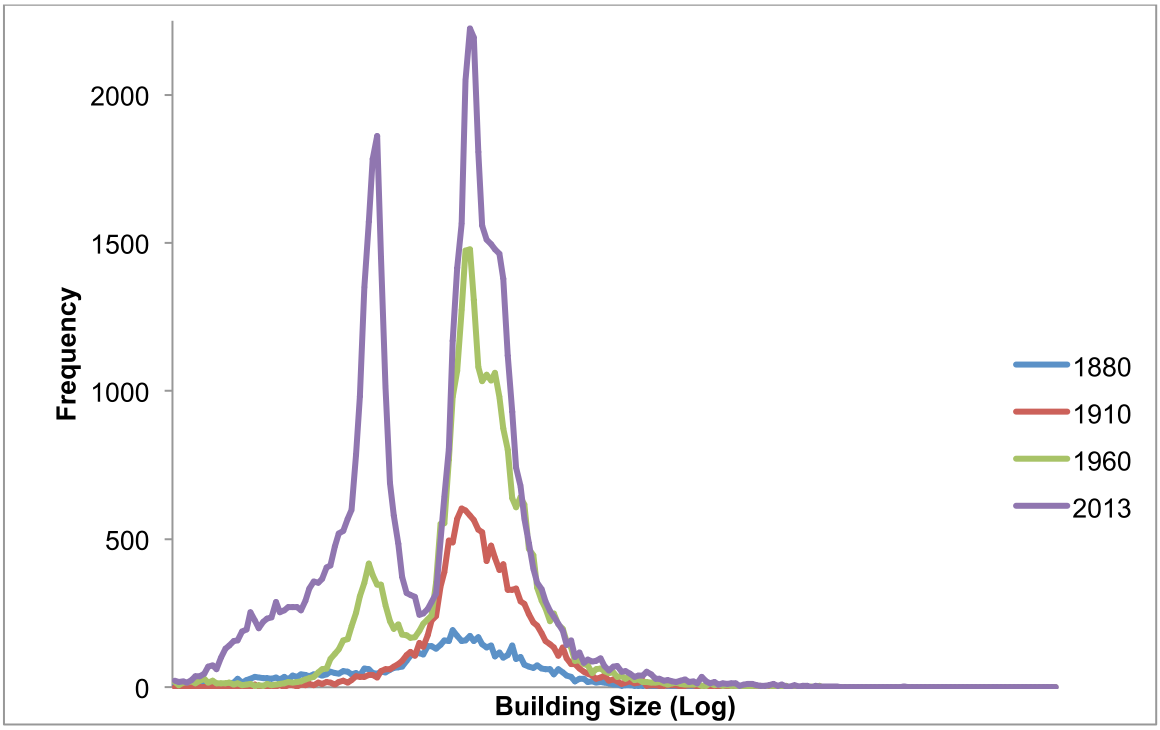
Graph 5 Changing average building size over time (m^2)

7.3.2 Development of New Typologies of Buildings

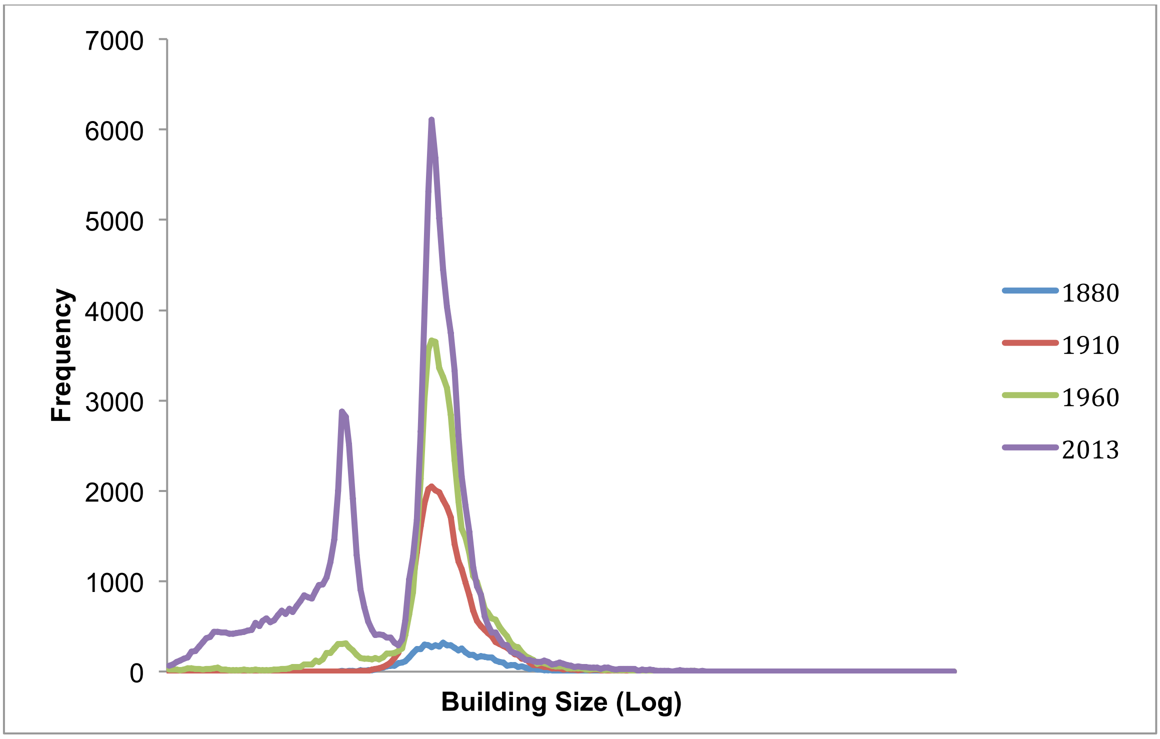
As shown in the previous section the changes in the built landscape in the two case study areas indicate that the buildings themselves have evolved over time to accommodate the development of London as a whole and the greater demands to provide accommodation and services to a growing population within a constrained area. This was shown to be achieved by the densification and declining average size of the building. To further investigate the changing buildings graphs 6 and 7 show the frequency distribution of building footprint size in Surbiton and South Norwood areas respectively, across all time periods of analysis. On these graphs the building footprint size is logged to reveal the underlying pattern in the distribution that is obscured by the exponential distribution of building sizes in both cases across all time periods.

Within these frequency distributions the same pattern of change over time occurs, in the earliest period of 1880 there is a lognormal distribution in both cases with the peak of values representing the domestic dwellings that account for the majority of the buildings with sizes mainly in the range of 40 to 70m^2 footprint area. This distributional structure persists in 1910 when there has simply been a growth in the number of building, which are present in each case and still show a lognormal distribution. It is in the 1960 period that this distribution changes significantly.

In the 1960 period as can be seen in the graphs of both case studies a secondary distribution appears in the footprint size distributions. This is refereed to as a secondary distribution as it is completely separate from the principal peak in values that account for the most common building that is the domestic home. This indicates that a new typology of building appears between 1910 and 1960, these structures are mainly 10 to 18m2 in footprint area. In the period from 1960 to 2013 in both Surbiton and South Norwood this secondary distribution grows, in the case of Surbiton even more so than in South Norwood. Whilst there is the emergence of a new size typology of building from 1910 onwards the principal peak in building sizes remains roughly constant, indicating that the earlier analysis that showed a reduction in the average building size is the result of these new building being constructed in conjunction with increased density, rather than a drastic shrinking in the average size of the main components of the overall building composition.



Graph 6 Changes in distribution of building footprint sizes in Surbiton (log)



Graph 7 Changes in distribution of building footprint sizes in South Norwood (log)

In order to understand the buildings that make up the new distribution of smaller buildings within the built environment in both cases it is necessary to map the values from the graphical analysis back onto the geospatial data. The results from this are shown in figure 3. In this figure the buildings that account for the new peak in the size frequency distributions are shown in green for a section of the Surbiton study area. The buildings that are identified as making up the centre of the new, first peak in the footprint size distributions are garages designed for the storage of motor vehicles, in this section located on back-alleys behind domestic dwellings.

This finding is surprising in that the impact of the development of garages of the extent to their growth has not been widely documented as an important stage in suburban development within the UK context apart from in the work of Whitehand (1991, 1999, 2001) and Clapson (2003), yet this analysis indicates that besides densification it is the most important shift in the make-up of the built landscape over the last 130 years. In 2013 within the two case study areas buildings of this size, that are principally composed of garages, account for 4.7% of the total built area in South Norwood and 5.4% in Surbiton. To understand this shift it is necessary to look back at the previous chapter and the analysis of the changing syntactic structure of the case studies, especially Surbiton and High Barnet, in both these cases between 1910 and 1960 the largest shift that occurred is the development of large road infrastructures, such as the

Kingston By-Pass. When seen in conjunction with the building analysis it is clear that there are two processes at work in the urban environment between street networks and buildings at the individual, domestic level. Whilst the road infrastructure is reacting to planning ideas about movement efficiencies in the city and access in an ever growing and densifying metropolis, and the car is becoming attainable and available as a personal possession the buildings also develop so as to be able to accommodate the personal mobility technology into the daily lives of the population of the city by the construction of buildings to accommodate the motor vehicle. These synergies between the developments of the street and road network, technological development and availability and the built environment are here clearly demonstrated to be interlinked in a system of interdependencies that brings about changes from the city-scale through to the level of the domestic home mediated by complex interrelationships.

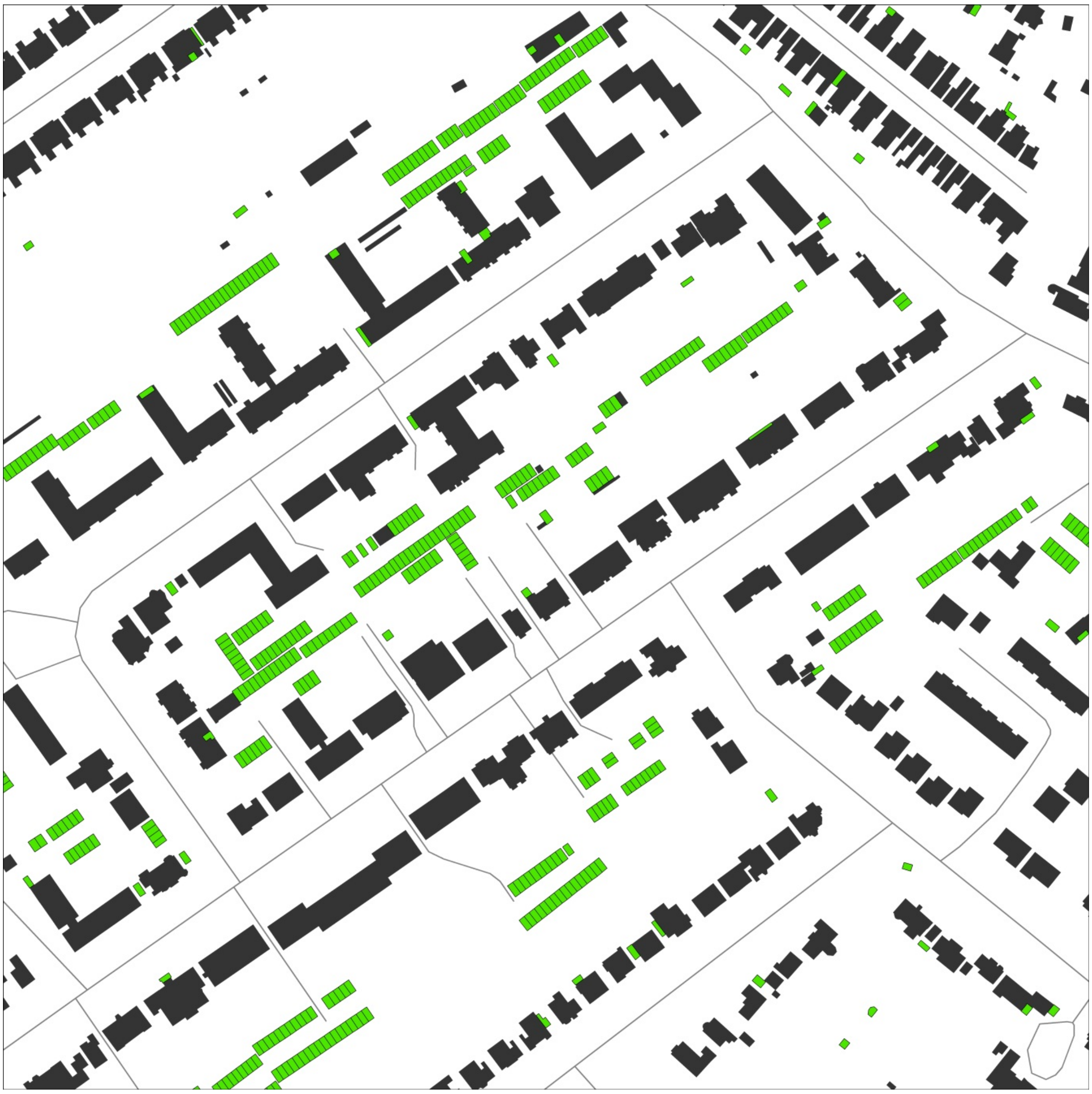


Figure 3. Identified buildings making up new first peak in building footprint size distributions in Surbiton. Identified as garages.

7.3.3 Building Size Distribution Change

Whilst the analysis in the previous section looked at the overall change in the structure of the composition of buildings it was not capable of creating a visual understanding of the process of building development that the case study areas have experienced as a whole. Using the structure of the distribution in graphs 6 and 7 it is possible to classify the buildings into three main categories based on the frequency distribution. This approach yields three main categories of building sizes, the small buildings and garages that make up the first peak in values (small), the central peak in the distribution that is primarily composed of domestic homes (medium) and the tail of higher values beyond the central peak (large). This categorisation can then be applied to all time periods and built structures to see how the different size classes of building have developed over time.

In figure 4 this method of visualising the built from size change over time is shown for the Surbiton area. This visualisation provides a new form of visualising the changing structure of the size of built structures over time that is based on the distributional structure of the data. Using this visualisation method the changing patterns of building development become immediately apparent. In both case studies in the time periods from 1880 to 1910 and 1910 to 1960 the primary growth that can be seen is in the middle size range in the construction of buildings at the domestic home scale. In the period from 1960 to 2013 the growth changes its focus and buildings within the larger category grow at a far larger pace. The locations where this occurs are important as it can be clearly seen that there is an uneven spatial distribution of the largest buildings. In Surbiton over time three locations of clustering can be seen; the most significant cluster that develops over time is the one to the north around the town centre of Kingston (figure 5). The other two clusters are in the northeast and south of the study area. The one in the northeast is a sewage treatment works and the cluster in the south is an industrial area or warehousing (figure 6). Importantly the industrial area in the south is directly adjacent to the Kingston By-Pass that is present in the data from 1960 onwards. In the 1960 period there is already some clustering of the larger buildings in this area and this clustering continues to develop.

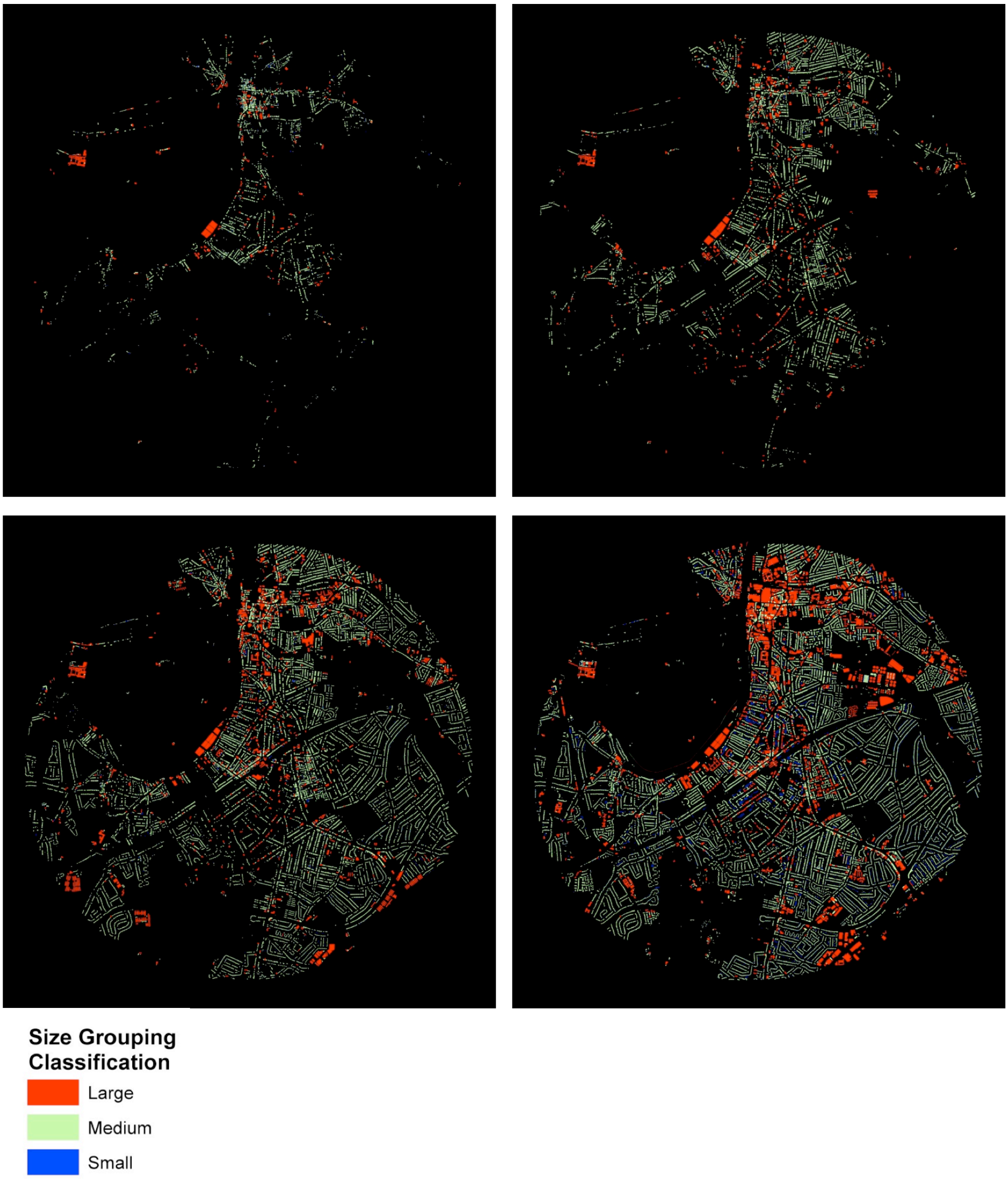


Figure 4 Building size category changes over time in Surbiton.

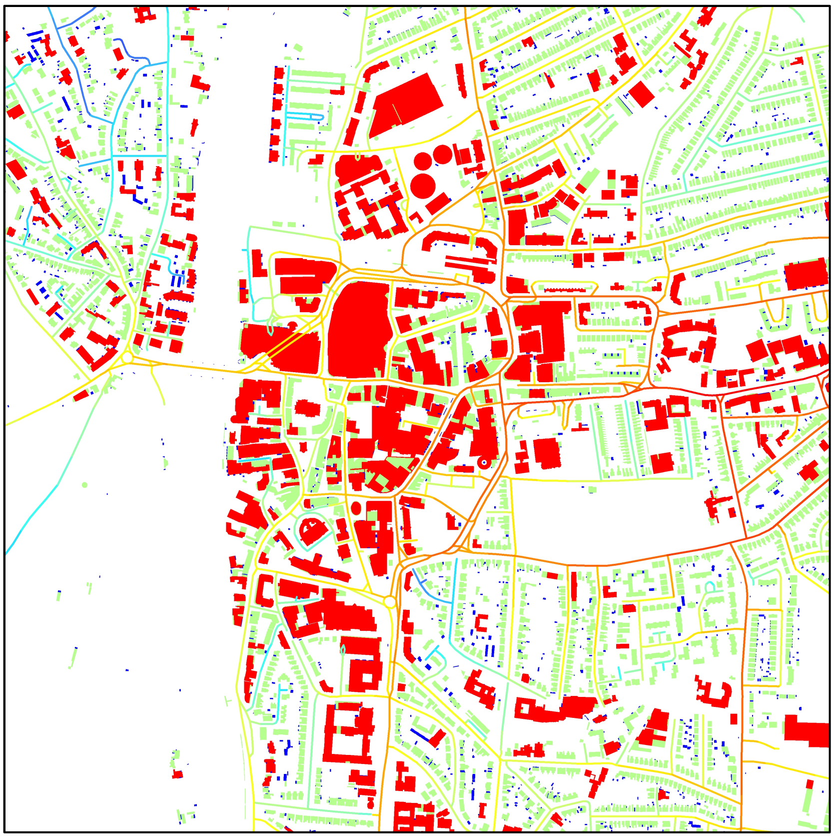


Figure 5 Clustering of large buildings around Kingston town centre overlaid on Integration radius 3000m street network

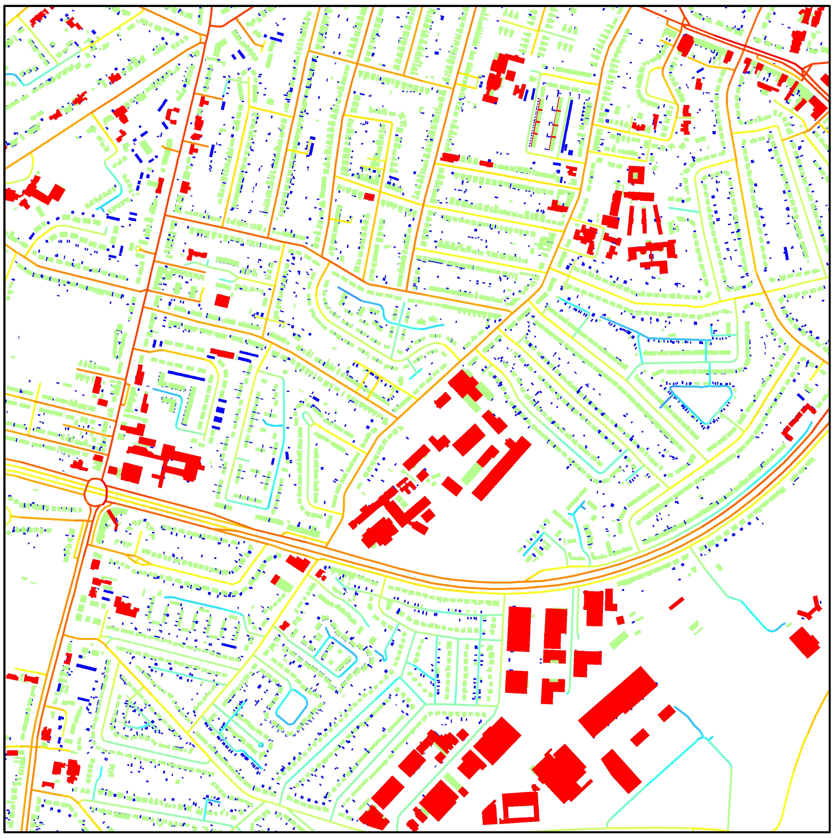


Figure 6 Clustering of industrial buildings around Kingston By-Pass overlaid on integration 3000m street network

The clustering of these buildings around specific locations within the network indicates the strong relationships that exist between network properties and the buildings that they are related to. Industrial activities seeking high accessibility locate near the By-Pass in order to exploit the high choice properties of the network that increases the their own accessibility and the accessibility of other locations that might be of relevance to their commerce. In South Norwood, as shown in figure 6 there is one principal location where the largest building develop over time in the southwest of the study area. This are is the centre of Croydon (figure 7) that is the principal commercial centre in South London. In addition to the primary cluster around the centre of Croydon large buildings also develop on the straight route running northwest from there. This is the road that leads directly towards London and is an important route, which generates high levels of both choice and integration due to its configuration. The development of larger buildings that can better exploit the land area and their network locations a system of interrelated developments in the fabric occurs where the buildings and street network co-evolve to maximise the efficiency of the system by exploiting the affordances of the network. The clustering that can be seen in the largest category of buildings also mirrors the concept of foreground and background networks, the largest building make up the foreground of buildings against the background of residential buildings. They can also been seen to mirror each other in creating a foreground of both network and buildings. The structuring over time of a the urban fabric points towards a self organising principle that tends towards a locating of the largest buildings on the network locations with the highest centrality due to the accessibility that is afforded by these locations.

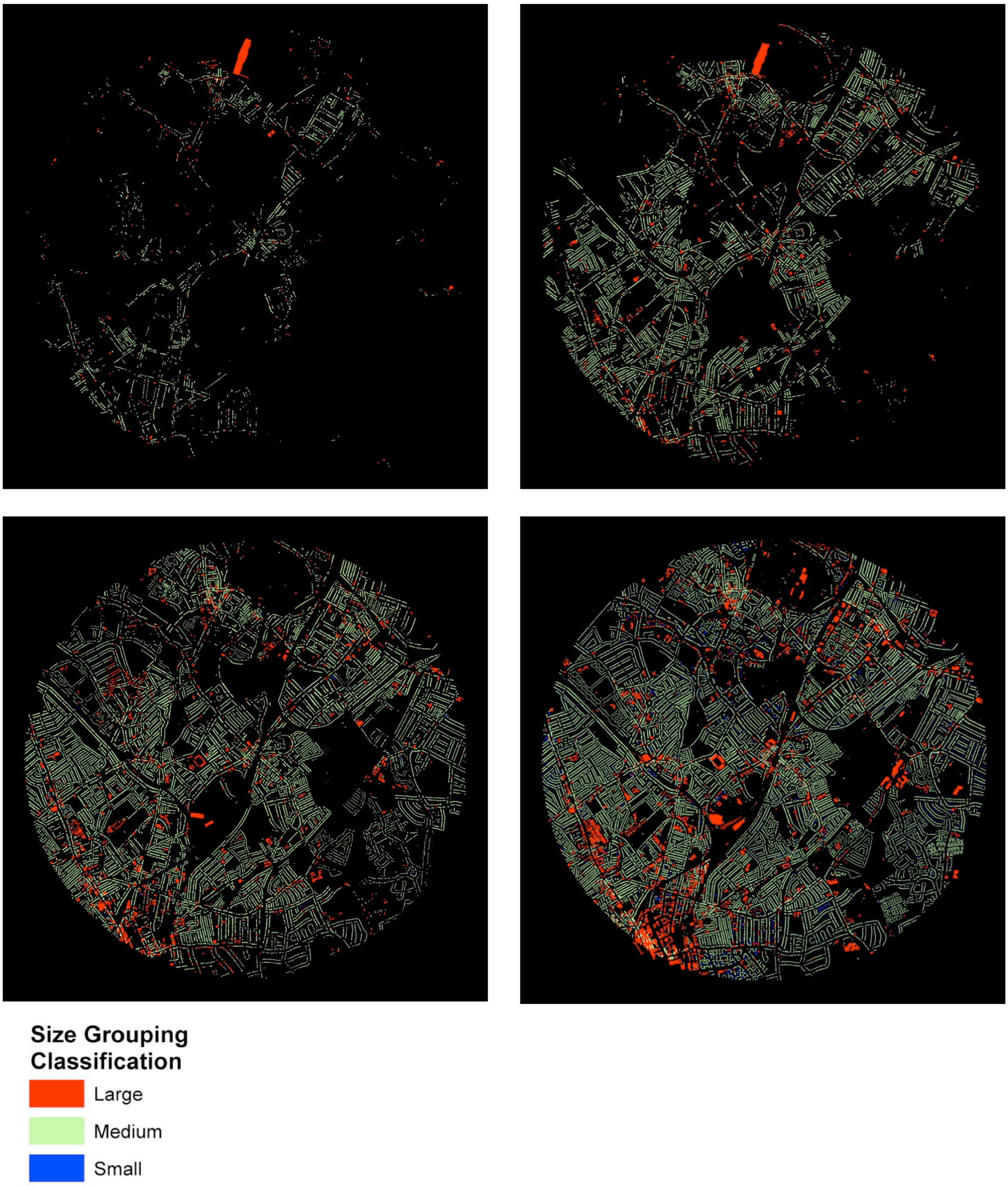


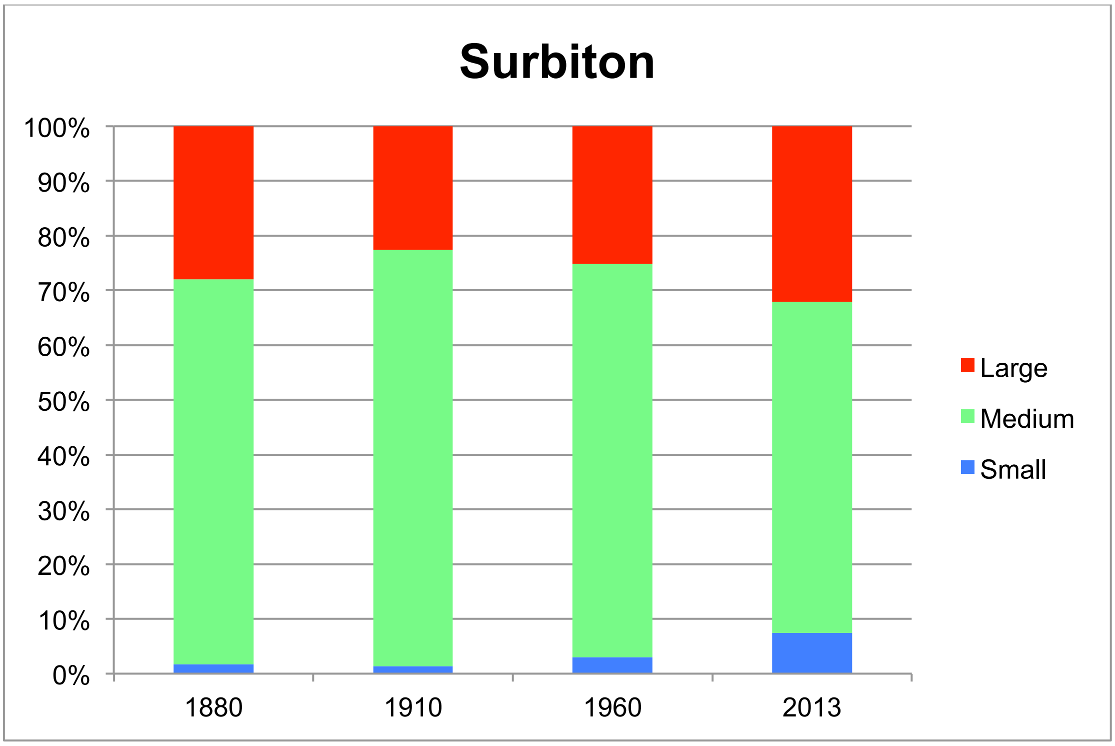
Figure 7 Building size category changes over time in South Norwood

Figure 8 Clustering of large buildings around Croydon town centre and road leading northwest towards central London overlaid on integration 3000m street network

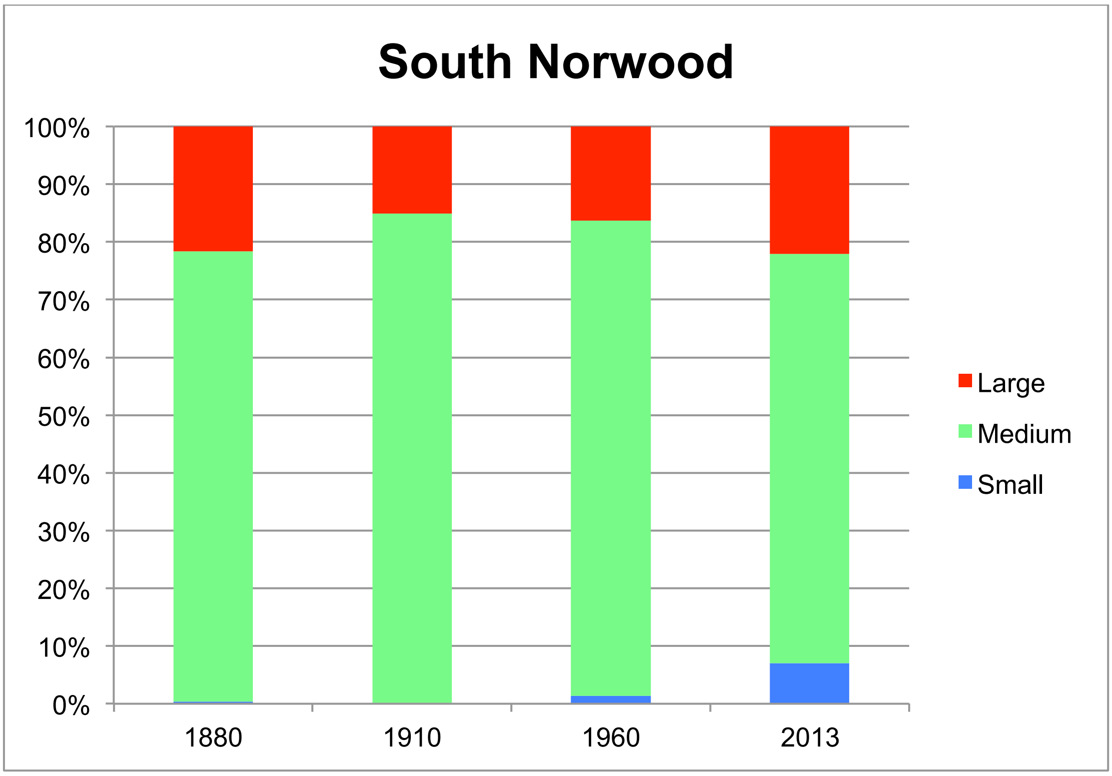
In graphs 6 and 7 the structure of the built from is charted according to the three size classes structure. These charts show the changing composition of buildings over time. Strikingly in both cases they follow near identical trajectories of change, albeit with differing proportions of each size class. An assumption would be that there may be defining local characteristics that inform the development of the buildings in specific areas, but these graphs indicate that both areas experience the same pattern of building development over 130 years across the size classes.

In both case studies in the earliest period the middle size category ranges from 72% and 78% in Surbiton and South Norwood respectively, the smallest size category makes up 2% to 1% with the remainder being the largest size category, accounting for 26% and 21%. In 1910 in both cases the proportion of the largest size class shrinks to its lowest level due to the rapid expansion of residential buildings as the development of suburban London takes place. In 1960 this pattern has started to shift with the expansion in the proportion of the largest buildings and the emergence of smaller buildings, principally made up of garages as shown earlier. This pattern of development then continues up to 2013 when the proportion of the largest buildings grows, as does the small buildings. The built landscape in 2013 contains the lowest proportion of residential sized individual dwellings of any period.

Analysis of the changing size composition of the built fabric in the two case studies shows that whilst there are clear trends in the pattern of development, the buildings evolve to accommodate differing needs of period. When London's suburbs initially expanded between 1880 and 1910 the primary driver for building development was that of residential accommodation, so correspondingly we see the greatest growth in the size category of buildings. In the following period up to 1960 as the population and residential buildings continue to expand two changes in building development occur. Firstly the largest size category of building expands, likely locations providing services and a greater variety of locations for commercial usages as the locations of commerce expanded from the historic core of London, in tandem with this the smallest category of buildings also expand at an increasing rate, which includes garages. This trend continues into 2013 with more garage-sized building developing and the continued expansion of the largest size buildings. Furthermore the similarities in the stages of development between the building sizes and junction and dead-end development documented in chapter 5 are striking. Both show a change away from the pattern observed in 1880, but then a return over time by 2013, when the situation resembles more closely the 1880 period. This shift away-and-back is suggestive of suburban expansion being an anomaly in the urbanization of the peripheral areas of the city, with a natural organisational structure to both the buildings and network structure reasserting itself over time once the rapid large-scale planned expansion of the inter-war period came to an end.



Graph 8 Surbiton changing building size composition



Graph 9 South Norwood changing building size composition

Considering the overall change to the structure of the built landscape and the stages of network development documented in earlier chapters the dual evolution of buildings and street network is how an understanding of the morphological development of urban areas needs to be considered. By understanding the concurrent development stages it becomes clear that they are part of the same organisational system of spaces for human activities that whilst changing constantly have universal properties that allude to an optimal organisational form emerging over time.

7.4 Land Use Change Over Time

The previous sections have examined the nature of the building development in Surbiton and South Norwood by describing both the overall pattern of development and by the classification of buildings by footprint size, and the associated change in proportions of specific building form sizes. Whilst this captures the changing structure of a large area, understanding how the changes in the utilisation of buildings has not been explored. In this section the reconstructed building record is combined with data created by the Adaptable Suburbs project team to capture town centre land uses over time. This dataset was created by digitising and georeferencing business directory data obtained from historic record research and fieldwork carried out by members of the research project. This data was collected so that the dates matched as closely to the map data that was used for the reconstruction of the building footprints. By bringing these two data sets together it allows for an understanding of the ways in which the buildings were used on the ground and how this has changed over time. The town centres are locally important centres of activity and the types of activity that are occurring in the buildings in and around them were to allow insight into the ways in which they were being used in a given period and how changes in how society use local commercial spaces reflects changing needs and economic relationships in spaces of the everyday.

7.4.1 The Changing Composition and Form of the High Street

In figure 9 the town centres of South Norwood is shown for the time periods of 1880, 1910, 1960 and 2013 with the building coloured according to their usage indicated in the key, the maps of each time period are presented at the same scale. Graph 10 shows the building mass change over the time period and graph 11 shows the proportion of land uses for each time period. Examining these figures and graphs it can be seen that firstly the commercial centre referred to as the high street in the UK is not a static entity but a dynamically changing assemblage of buildings serving different purposes over time. Firstly the built mass of buildings with non-residential uses increases from 11,000m^2 to 29,000m^2 over the 130-year period as building structures expanded and new larger premises are developed. This can also be observed in figure 9 where larger buildings appear over time in the town centre in 1960 and 2013.

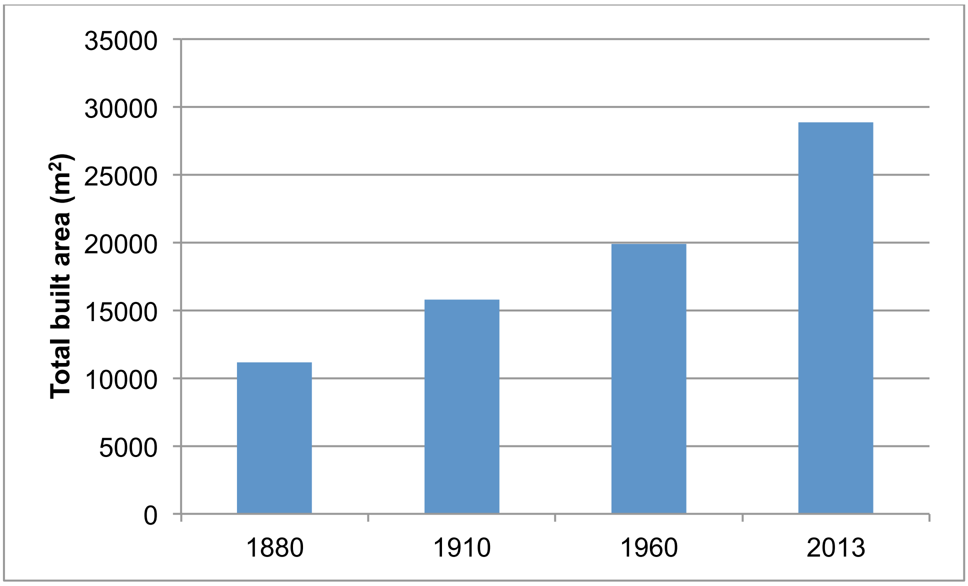
Whilst there is a densification and expansion in the mass of the buildings the real value in bringing together the land uses and buildings is to understand the uses within the buildings. In graph 9 the proportions for the land uses are presented. The high street in the UK is synonymous with retail activities; this data shows that in South Norwood this is an incorrect characterisation in all time periods. Whilst the retail class of land uses is the largest individual land uses it never significantly exceeds 50% of the land use and in 2013 it is significantly less than this. The peak retail point is in 1910 when it accounts for 51% of building land uses and then declines from then to the current level of 38%. This is striking in that much policy is orientated around the premise that the high street is a place of retail consumption when in actuality, currently it is primarily serving purposes other than retail. The other commercial class of land uses such as offices and professional services fluctuates over time maintaining an approximately steady proportion of land use from 1910 to 2013. Community services such as schools and libraries emerge first in 1910 and stabilise just above 10% of land uses in 1960 and 2013.

The two reaming classes of land use are particularly interesting in relation to how people use the high street and the forms of economic production and consumption that they indicate are taking place. The manufacturing class of land uses accounts for 9% in 1880, rising to 15% in 1910 and then declining from to 7% in 1965 and 3% in 2013. Manufacturing in this classification system takes into account and kind of industrial manufacturing process and softer manufacturing, such as tailoring, boot making and haberdashery. The presence of manufacturing in and around small high streets in the past is important in understanding that the high street was also a place where production and value creation took place and where people with particular skills could apply their craft to earn a living. This is very rarely the case nowadays as indicated by the sharp decline in manufacturing since 1910.

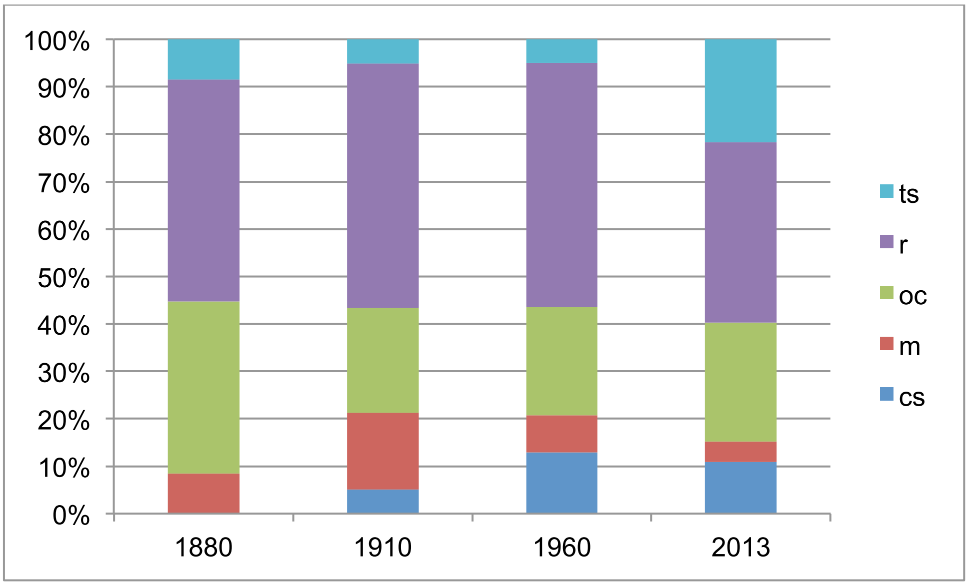
The remaining class that has the most ambiguous name is Third Space, this classification is used to take account of all the land uses that have the capacity for people to spend time in and socialise in. This includes cafes, restaurants and pubs.

The land use class has expanded the most across all time period, in 1880 is accounted for 8% of land uses, in both 1910 and 1960 it was 5% and then by 2013 it accounts for 22%.

Figure 9 South Norwood town centre land use change over time



Graph 10 South Norwood town centre built mass change over time



Graph 11 South Norwood town centre land use composition change over time

Whilst the analysis of South Norwood highlighted specific trends in the at area when Surbiton is also considered it can be seen that these trends are present across both cases, strengthening the argument that the high street is a dynamic place adapting and changing to economic and social demands. In figure 10 the land use maps for Surbiton town centre are presented and in graphs 12 and 13 built mass and proportions of land use are shown respectively. In terms of built mass within the town centre there is an increase from 25,000m^2 to 68,000m^2 over the time period of study, roughly matching the approximately three-fold increase in built mass seen in South Norwood. From the maps in figure 8 it can be seen that there is also an expansion of larger buildings in the 1960 and 2013 periods, similarly to South Norwood.

In regards to the changing proportions of uses the same pattern as in South Norwood is observed, retail in this case also peaks in 1910 at approximately 51%, which is maintained in 1960 and then declines to 35% in 2013. Manufacturing also declines from the peak in 1910 of 15% to 2% in 2013. This further reflects the changing structure of manufacturing and production to a global scale operation that has moved manufacturing industry and the associated skills away from locally based individuals. The emergence of community services comes about in 1910 at 2% and increases to 12% in 1960 followed by a decline to 11% in 2013. The category of other commercial is largest in 1880 at 35% but then remains stable at around 23% of land use.

Again as seen in South Norwood the class that experiences the largest growth over the whole period of study is that of third space (Oldenberg, 1989). Rising from 8% in 1880 to 22% in 2013. This is the most significant shift in land use seen in both cases across all time periods, alongside the decline in retail and to an extent manufacturing. The decline in retail can be accounted for by the changing practises of consumption and more economical alternatives have emerged, the manufacturing can also be attributed to the globalisation of manufacturing to exploit cost efficiencies offered by manufacturing in locations with low labour costs which has been facilitated by global transportation capabilities. The growth of Third space on the other hand demonstrates how the local high street is being utilised when the space is freed up from other land uses.

The fact that Third Space has seen the greatest level of expansion is indicative of both consumption patterns and the uses that the high street serves to the local population. In recent years retail consumption has increasingly been conducted away from the high street with the traditional shops of the high street suffering as a result due to declining sales. It would appear from the data that the decline in retail has been absorbed by the expansion of the Third Space class. People's uses of the high street have shifted in line with the changing retail environment, whilst before people may have had to use the high street for utilitarian retail functions, now with alternatives that are more economical the spaces of the high street are being used from social activities and other activities based around spending time in a place where you can carry out leisure or work activities. This re-socialisation of the high street suggests that it is primarily a social space, and given the opportunity to orientate towards this, the space that was previously occupied by retail will be transformed to enable this usage.

In relation to the spatial understanding of the functioning of urban networks offered by urban and space syntax theory this transformation can be clearly interpreted. The street is understood to the egalitarian, as much as possible, space of the public. In these spaces flows occur of people moving through the city, creating differing levels of co-presence in different space according to the affordances of the configuration of the street network. The co-presence on the street acts as a low level of interaction between the people who are sharing the space. Whilst the functions of the high street have historically, as shown, been dominated by functional uses by people to fulfil daily needs the transformation of the possibility to fulfil these needs in more economical means that occur away from the high street has freed up the built from for other uses, and they have been occupied by uses that provide a social space for interaction and co-presence to occur alongside the street that had previously been the primary domain of this function. The location of the high street retail functions has been shown to relate to the spatial configuration, in that locations of retail activities coincide with higher levels of centrality in the street network. What we can see in this analysis is that the locations of high centrality that are indicative of higher levels of through and to-movement and the associated co-presence are being transformed also in the built environment to spaces for co-presence and social interaction to occur, spreading spaces of socialisation from the street into the buildings. This accumulation of space for social interaction further indicates that in the development of the city a primary driver for both its transformation and success is the creation of spaces where exchanges between individuals occur, and that the city functions to bring people together and generate exchanges, both economic and cultural, and by accumulated changes across multiple domains of influence on the shape and structure of urban form the social spaces of the city have expanded creating a continuity of social spaces, from the street into the buildings.

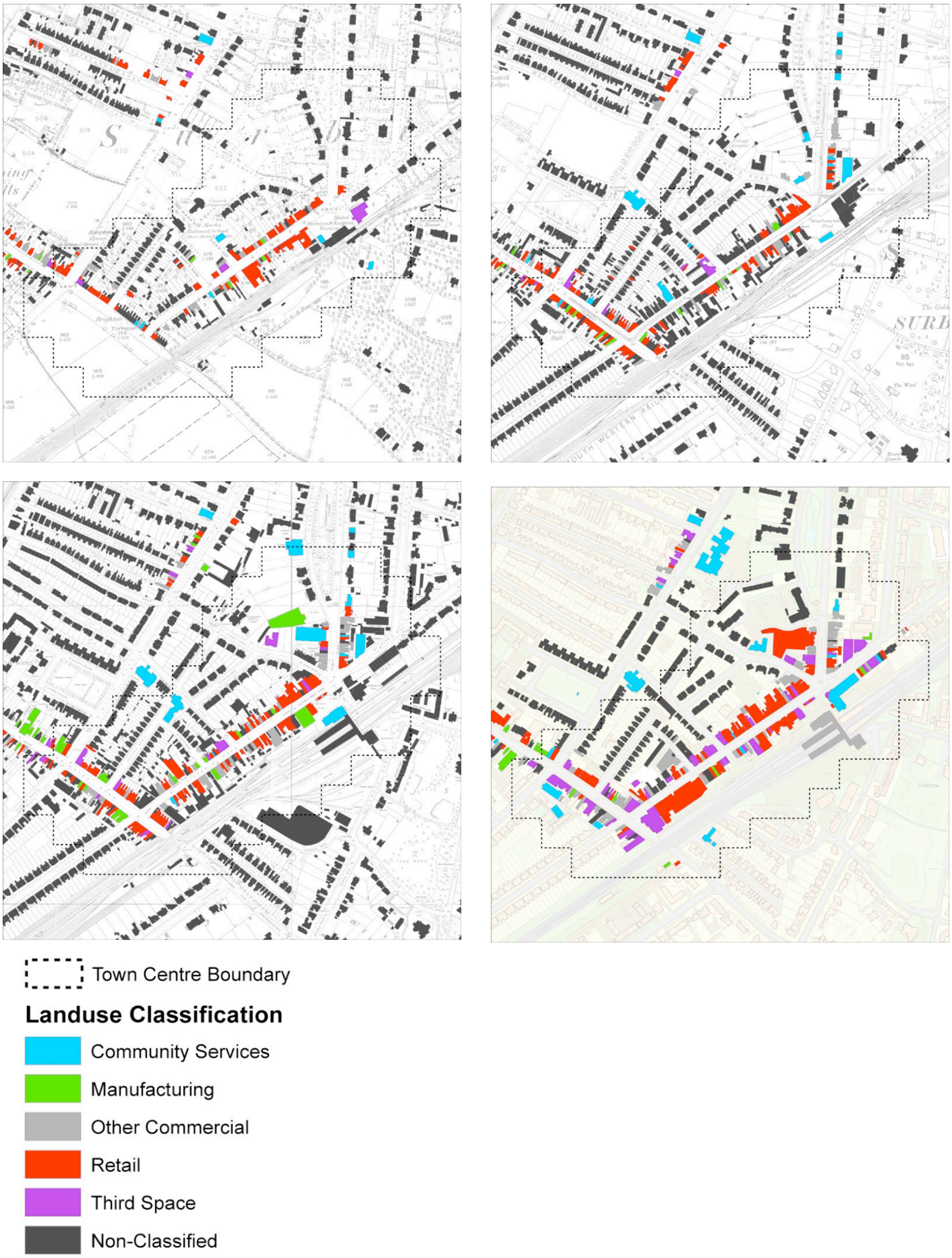
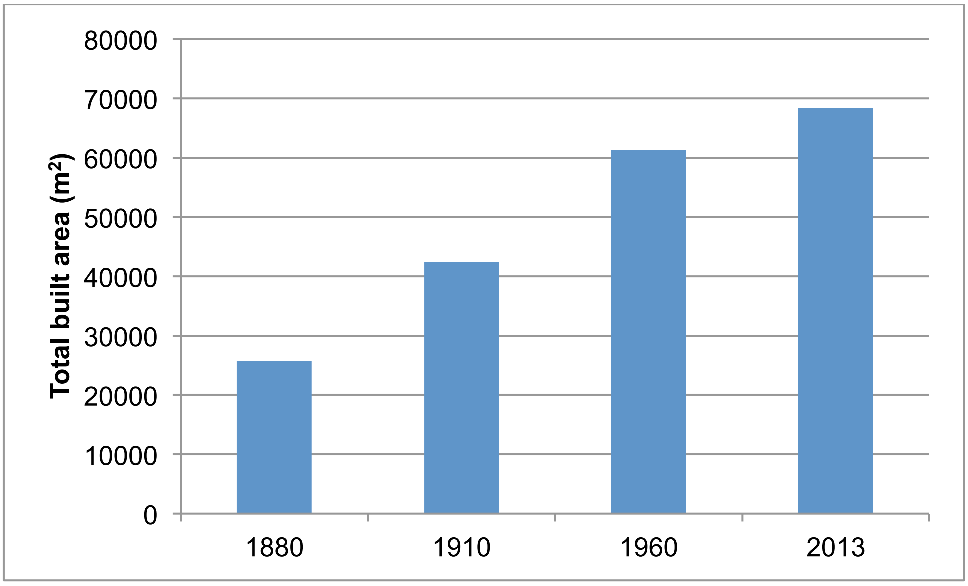
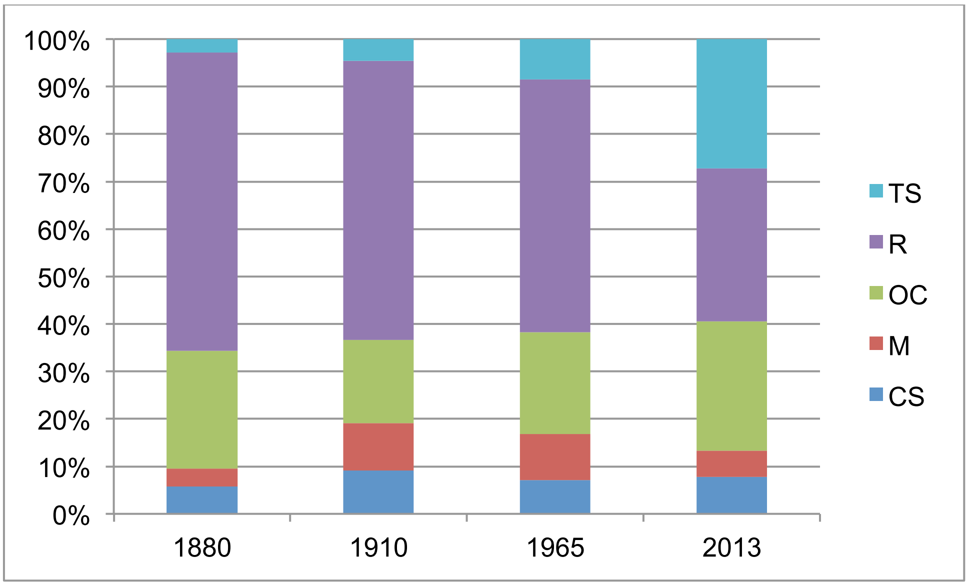


Figure 10 Surbiton town centre land use change over time



Graph 12 Surbiton town centre built mass change over time



Graph 13 Surbiton town centre land use composition change over time

7.5 Summary

This chapter has presented the analysis of the changing make-up and form of the built environment in Surbiton and South Norwood over the last 130 years. From this analysis it is clear that significant changes in the overall structure and typologies of buildings have occurred over the period of analysis. In relation to the street network the growth in the mass of buildings has been significantly higher, showing a non-linear relationship with a constantly increasing ratio of built area to network length. This developmental relationship suggests that the street network, as the structure that supports activities that happen between locations situated in buildings, has a far greater capacity than is utilised in a given period, and that as an area is urbanised the excess capacity in the network is used, and incremental increases in network length provide ever-increasing capacity for buildings. This is suggestive of the pre-existing network capacity being a prerequisite for urban growth. The spatial structure of building development also showed a clear pattern. In the earliest periods of 1880 and 1910 in both cases the spatial structure and development of the built-up areas was such that it connected local centres in corridors of continuous urban fabric. In the later periods, when rapid outer London expansion took place this changed as the whole area was populated with buildings. This marks two clear stages in the development of the buildings of the two areas. The first stages were the incremental local growth, whilst the second stage was the merging with the London urban region as a whole and represents the complete urbanisation of the areas. This two-stage development is important, as the early stage of building development patterns will still be present in the later stages, reinforcing the relationship between local areas by the structuring of the newly built urban fabric around the historic development patterns.

In the analysis of the changing distribution of building sizes it was shown that a new typology of building sizes appears in the data from 1960 onwards in both cases. This new typology was found to be principally composed of garages for personal motor vehicles. This change is particularly significant as it coincides with the development of large road network infrastructures shown in earlier chapters, illustrating the interdependencies between forms of network development, building evolution and technological development. From this analysis the structure of the size distribution was use to construct size categorisations of the buildings. This showed that the residential expansion from 1910 to 1960 changed the size composition of the buildings, but that by 2013 the composition had returned to levels in line with the situation in 1910 in relation to the middle sized and large buildings. Furthermore the largest buildings were shown to cluster in specific locations around areas of high centrality in the network in both Surbiton and South Norwood. This clustering of the largest buildings around the location of highest centrality indicates that there are strong dependencies between built-up areas and the configuration of the street network. It is suggested that the idea of a foreground and background network structure can also be applied to the buildings in a similar theoretical manner.

The final section presented the findings of historical land use surveys, integrated with the historic building footprint records for the town centres of Surbiton and South Norwood. An examination of the changing composition of the land uses showed a change over time, towards uses that have been suggested to have more potential for social exchange, interaction and production (Oldenberg, 1997), indicated by a rapid rise in land uses classified as third space. This shift in the usage of the town centres towards spaces with potential for socialisation, away from retail, suggests that as other activities that have traditionally taken up space within town centres have moved to other locations or mediums, the social space of the street has been extended into the buildings located in the most locally central areas, creating larger and more varied locations for socialisation. This suggests that one central utility of the city, as it has evolved over time, is to structure and afford the potential for exchanges between people. In the analysis of buildings the necessity of a joint understanding of street network and building development to understand the nature of urban development across all its physical manifestations was shown.

Key Findings:

- A non-linear relationship was found between the network length and built area as it developed over time. The built area constantly increased at an increasing rate relative to network growth.
- The spatial development of the built landscape demonstrated two stages, the initial incremental growth around and between local centres, followed by growth across the spatial extent of the study areas.
- A new typology of building was shown to emerge in the 1960 building record in both case studies. This new building type was identified to be the garage.
- The analysis of the composition of building sizes showed that over the course of the analysis the ratio of building size classes fluctuated, returning to levels similar to 1880 in 2013, after a period of residential-sized building domination.
- The analysis of land use change over time showed that the most significant shift has been the strong emergence of land uses classed as third space in the period 1960-2013 in both case studies.

8 Discussion

8.1 Introduction

The preceding four chapters presented the analytical and methodological outcomes of this research. In chapter 4 the data that this study uses was evaluated to understand the impact that different network representations have on space syntax network analysis techniques. This analysis showed that road centre-lines can be used successfully in space syntax research and that certain aspects of this form of data representation have advantages over axial modelling, specifically the detail of interconnections and geometry that they contain. The novel methods presented in chapter 4 for the reconstruction of building footprints illustrated the advantages of approaching problems from the perspective of multiple disciplines, in allowing research to be carried out effectively by combining techniques and approaches to data creation and extraction for research purposes. Chapter 5 though 7 presented the analysis of the contemporary and historical data of the four suburban case studies. Chapter 5 presented an analysis of the network characteristics of the four case studies over time in relation to the contemporary street network of London, and their syntactic properties in relation to centres within the core of the London area. Chapter 6 presented the historical analysis of the four case studies and further analysis of Surbiton and South Norwood. In chapter 7 these two case studies were then used as the locations for the reconstruction of the built form that was then statistically evaluated, in order to understand the changing forms and composition of the buildings that have populated the fringe of London over the past 130 years. In this chapter the key findings from the analytical section will be looked at in depth. The findings are not considered individually, but rather are brought together so that the relationships between these findings are clear. This is particularly important in this research domain, as none of the historical occurrences can be considered in isolation, but must be understood to be components of a continuously extending and evolving whole. It is suggested that the linkages between the phenomena that have been observed in the analysis allow the greatest insight into peri-urban development. In this chapter the findings are discussed under broad headings, reflecting their interconnectedness. The first section addresses the residential expansion of the case study areas, from the perspective of the overall street network and built form changes observed over the period of the study. The second section considers the impact of macro scale infrastructure development, and its relation to local infrastructures that have been found in the case studies. The third section examines the finding of the emergence of the garage as a new building typology, and the implications for discussions of mobility in the city. The fourth section then moves to the finest scale of analysis, considering the implications of high street land use change, in relation to how the uses of space have changed over time. The fifth section then considers the methodological developments and approaches that have been used to accomplish this research in relation to historical and morphological analyses. The sixth, and final section considers all the outcomes of the analysis together, to discuss the overall findings as a interrelated and coherent set of processes that manifest themselves on peripheral areas of cities as they develop both spatially and socially, within the context of technologically mediated spatial development. Certain graphs and charts are reproduced in this chapter to facilitate cross-referencing of findings and clearer explanation.

8.2 Summary of findings in relation to research questions

This research has explored the ways in which peri-urban London has developed over 130 years. This has been studied by analysing the configuration of the street network and the built form, and the relationships between them in order to answer the research questions set out in chapter 2:

'What are the morphological centrality and built form characteristics of peri-urban London as it has developed over the period 1880-2013?'

'How can GIS and Space Syntax research methodologies be combined and enhanced to enable efficient and detailed, large-scale historical analyses?'

With sub-components:
'What have been the patterns in the development of peri-urban London's street network in the period 1880-2013 and are there coherent structural patterns to this development?'

'How have the built forms that populate the street network developed over this period, and are there specific forms associated with peri-urban areas?'

The street networks of four areas; High Barnet, Loughton, Surbiton and South Norwood, on the fringes of the London urban region were reconstructed for three historical periods dating back to 1880, which were evaluated in conjunction with the 2013 street network. Using space syntax methods the development of the street network system was analysed to understand the configurational evolution of the study areas. In the case study areas of Surbiton and South Norwood the building footprint record was also reconstructed. The development of a novel data extraction technique allowed the entire building footprint record to be created for the two case studies across all historic periods. This dataset enabled the research to analyse the changing composition of the built form in conjunction with the street network. This made it possible within the analysis to understand the urbanisation process from both the perspective of the street network and built form, and the relationships that exist between them as they co-evolve. In order to be able to carry out this research significant data research and evaluation was conducted to ensure that the research was as rigorous as possible in the representations that it used in both the reconstruction of the historical building records and the street networks. Only through the novel and rigorous foundation to the data sources and their creation was this expansive and detailed research possible, as discussed in chapter 4, addressing the question of; 'How can GIS and Space Syntax research methodologies be combined and enhanced to enable efficient and detailed, large-scale historic analyses?'

In the analysis of the changing spatial configurations and network properties of the case study areas in chapter 5 and 6, addressing the research question of; 'What have been the patterns in the development of peri-urban London's street network in the period 1880-2013 and are there coherent structural patterns to this development?' the specificity and generality of their development was uncovered. All of the areas that were analysed underwent urbanisation to varying degrees, and in differing spatial forms. In High Barnet and Loughton the networks grew in their coverage and density, yet in 2013 there remained large areas of open space, where few routes have opened up certain areas to fuller urbanisation. In the case of Loughton it is constrained by protected woodland it adjoins, whilst High Barnet does not have these constraints yet is also only partially urbanised. In Surbiton and South Norwood the process of urbanisation from the perspective of the network development was far more advanced than the other two cases. This was the case in South Norwood in particular. South Norwood developed a strong configurational divide between two halves of the study area highlighting the uneven nature of development of the street network. Within all the case study areas the locations of growth varied over both time and space during the periods that were analysed. Yet amongst the difference there were also features to their development that were common across all the cases. The stages of network development were revealed in the analysis of the relationship between junctions and dead ends within the network. In this analysis it was shown that at different stage of the network development the balance between the construction of junctions, connecting space, and dead ends reaching out from the pre-existing network varied. In 1910 across all cases there was the highest ratio of junctions to dead ends, highlighting this as the most significant stage in exploratory growth of the network. After this period the ratio declined, and the network consolidated itself through creating greater connectivity, returning to a state more similar to the pre-1910 period. The development in the composition of the built form also reflected these stages of development.

The space syntax analysis also revealed commonalities in the network development of the case studies. Across all the time periods the town centres of the case study area retained their concentration of high values for both choice and integration across the scales of analysis. The constancy of their centrality and configurational importance highlights both their adaptable and persistent nature. Through all the social and spatial development that the urban area of London has undergone during the last 130 years they have retained their importance, as centres within the local and wider urban context. Their configurations maintained the overlap between through and to-movement potentials that are considered to be vital in their socio-spatial functioning as centres of activity (Vaughan et al., 2010). This persistence suggests that as urbanisation takes place the importance of past centres in structuring the future configuration of the city is paramount. Indeed it was shown that these peripheral centres today, whilst not having the high to-movement potential of centres in the core of London, had almost equal levels of through-movement potential at the scale of the city, further highlighting their importance within the spatial structure of the city as a whole. The most significant, wholly new feature that emerged in the street networks in all the case studies was that of large road infrastructures, such as the Kingston By-Pass in Surbiton and the M25 in Loughton and High Barnet. The emergence of these large road infrastructures based around the motor vehicle, whilst having differential effects on the local configuration of the street networks, developed alongside new forms of architecture that were revealed in the analysis of the built form.

Analysing the street network reveals the configurational potential of the network to structure flows of movement. The movement that occurs within the network happens between and from locations that are located within the buildings that populate the spaces around the network. In chapter 7, the reconstructed building footprint record enabled analysis of the changing composition of the built form of peri-urban London over the 130-year study period, in order to answer the question; ‘How have the built forms that populate the street network developed over this period, and are there specific forms associated with peri-urban areas?’. This analysis showed that, similarly to the results of the network analysis, there were distinct stages in the development of buildings. In the earliest period between 1880 and 1910 the greatest expansion in the proportion of residential sized buildings took place. This mirrored the network growth patterns of exploratory growth, indicating the interdependencies between the street network and built forms in the urbanisation process. In the later period when the network consolidated by increasing its connectivity, the built form also consolidated by returning to a pre-1910 composition of building sizes. Notably, when comparing the rate of growth of the network against the area of built form that it served, the area of built form continually increased relative to the network. This suggested that the street network in a given period is capable of supporting more built-up area than there is at the time. This potential within the network to support future urbanisation is suggested as vital in allowing for the continual process of development and change that occurs in cities. Whilst the composition of the built form fluctuated over time, in the 1960 and 2013 periods a new typology of building was shown to emerge. This new built form was the garage, for storing personal motor vehicles. The coincident time frame between the development of this new building typology, and the development of large road infrastructures further highlighted the interdependencies in the developmental trajectory of the urban fabric from the ‘microscale’ (Whitehand, 2001) of the individual building, to the city scale of by-passes and orbital motorways. This relationship between the city scale and the lived-scale of the built environment illustrates that the symbiotic development of urban systems occurs across all scales, reflecting one another in their forms, and stages of development. The evolution of network configurations and the built form around new transport technologies highlighted the importance of movement as a driver for development on the urban periphery.

8.3 The impact on the urban fabric brought about by the residential expansion in peri-urban London

The peri-urban landscape of London, and developed urban areas more generally are widely considered to be characteristic of suburbia. The analysis has revealed certain characteristics of this urban landscape that allow greater insight into what the urban fabric of suburbia is made up of, what it is not and how it has changed. The analysis has shown that areas generically understood to be suburban are complex and dynamic places that have constantly adapted over time through changes to the configuration of their street networks, and buildings and their associated uses. Whilst they provide extensive residential space on the periphery of the city, often for people commuting for work into the centre of the city, they are made up of multiple spatial and built forms that create a rich tapestry in the urban fabric. This analysis can clearly state that suburbia is not simply a commuter belt, or benign fringe to the city proper, but composed of places that function socially and spatially in their own right with distinctive qualities relating to their spatial relationship to the urban region. Importantly, through the historical analysis the changing composition and relationships between built form and street network systems can be understood. This changing relationship over time is vital, in that it reveals the impacts that various stages of urbanisation have brought about to the case study areas and the spatial transformation and character of peri-urban London.

The most important single urban transformation in the period covered by this research in the case study areas, and in the wider urban-fringe of London, is that of the expansion of the city to create large areas of residential buildings that are connected by transport links to the centre of the urban area. The principal mechanism through which this growth was achieved was by the massive expansion of the UK railway network throughout the 19th and early 20th centuries. This was not a passive event; the railway companies acted principally in a commercial mind-set, understanding the urban fringe to be a commodity that could be exploited through the development of the railway system, and then profiting from the increased land values brought about by the creation of residential areas around the railway stations at the same time (Wolmer, 2009). As was recounted in the historical overview of the case study areas, the arrival and development of the stations in close proximity to the town centres played a vital role in their development. This is confirmed by previous research which shows a strong statistical correlation between rail network development and population densification, working in both ways and suggesting a positive feedback system linking the two factors (Levinson and Chen, 2007). In the case of Surbiton the place came into existence almost exclusively due to the combination of the arrival of the railway station, following the refusal by Kingston-upon-Thames to allow it to be located in its centre, and the commercially speculative development of the area around the station, based on its new potential as a residential commuter area. Whilst this research has not focussed on the railway system in its analysis of the development of the case study areas, the railway system in many cases is the starting point for the residential development of the areas into what they are today. This research dealt with the urban forms that emerged in these areas as a result of multiple factors, including the railway system. The confluence and changing relationships between forms of mobility infrastructure are dealt with in a later section.

This discussion approaches the residential development of the case studies through the historical analysis, in understanding it as a series of stages in the development of the areas and not a final state. In the context of urban development there is no final state, but a series of continual changes altering the trajectories and capacities of change. From the analysis it was shown that the development trajectory of the case studies was not linear. This was particularly in the case of the topological structure of the street network and the distribution of built form sizes. These two measures allow for an understanding of the impacts of the initial burst of residentially focussed urban development and the subsequent consolidation of the areas through differing development trajectories.

In figure 1 and 3 the changing ratio between junctions and dead ends, and the composition of building size classes is shown over the four time periods of analysis taken from chapters 5 and 7. In both these figures it is clear that these metrics illustrate that the trajectory of the spatial and built form development of the case study areas are not continuous along a particular trajectory, but fluctuate over time.

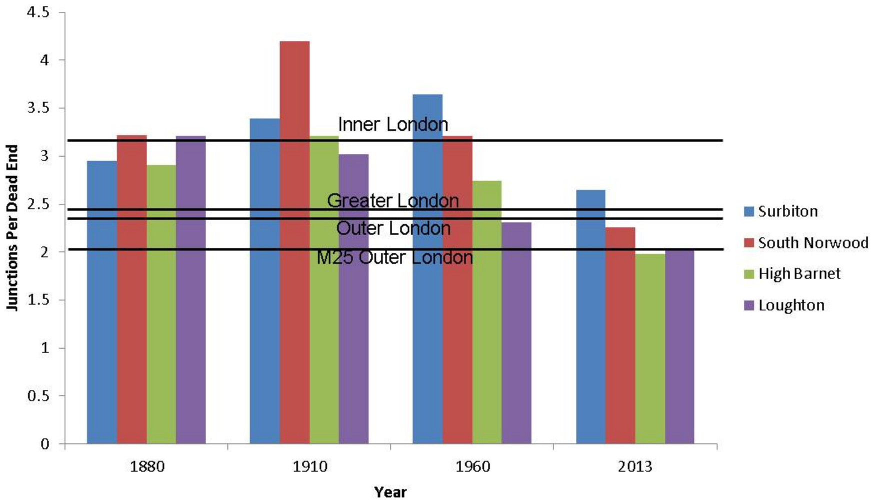


Figure 1 Junction to dead-end ratio change over time

The junction to dead end ratio in figure 1 demonstrates the topological impact on the street network of the primarily residential development that occurred in the case study areas. In the period of 1910 there is a significant spike in the ratio that then declines up to 2013. The development of the peri-urban landscape from semi-rural to a residential landscape requires the network to be structured as to accommodate as much space as possible, this leads to a system with many dead ends, as the network is in an exploratory growth state of expansion, entering and subdividing new territory as illustrated in figure 2. This process of subdivision has been shown in other work (Whitehand, 1999) whereby the existing parcels of land are divided up into smaller parcels to accommodate a greater density of buildings situated on separate land parcels. The division of pre-existing land parcels into smaller ones is significant in that the structure that results from the subdivision is a product of the spatial structure of the land ownership that existed before the subdivision occurs. This path dependence potentially implies that the structure of the land parcels in the contemporary city are rooted in patterns of land ownership that existed centuries before.

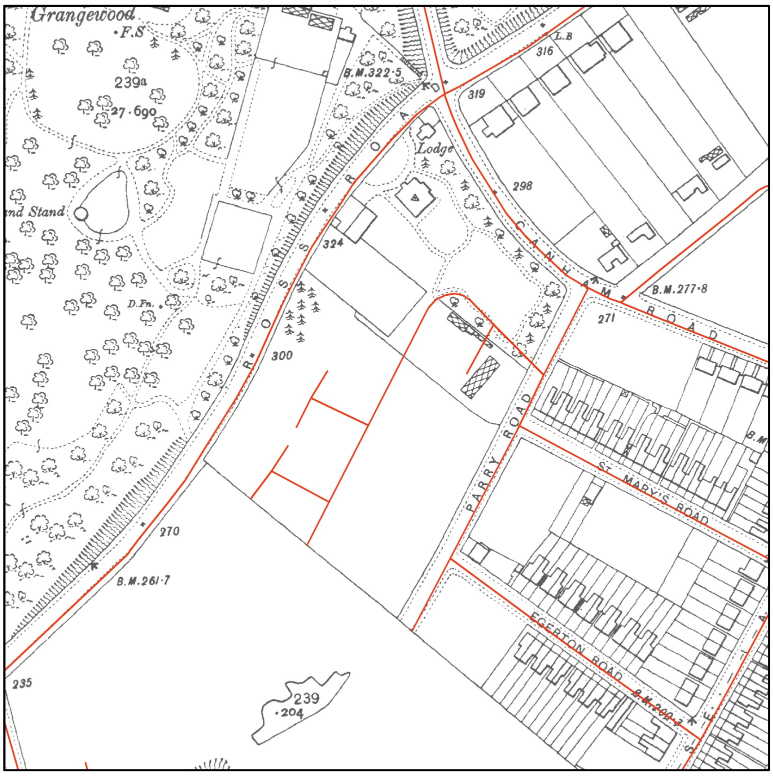


Figure 2 Map showing the development of dead-ends during network growth and parcel subdivision in South Norwood. 1960 network (red) overlaid on 1910 base map.

The unique residential expansion stage that begins in 1910 is corroborated in figure 3 showing the proportion of building sizes. There is a correspondence between the two graphs. In 1910 the peak of the dead end ratio is reached in most cases, and it is also the time period when there is the greatest proportion of the class of building made up principally of residential buildings. This comparison of the network topology and built form composition shows that the network and the built form are acting as one system that develop together. Importantly after the spike in both metrics of the built form composition and the network topology, they both decline. The decline is the most important feature of both metrics and is due to the reversal in the trend that existed between 1880 and 1910. Whilst the case study areas rapidly developed and became dominated by residential buildings, and a network of many dead-ends, this reversed and the topology of the network from 1960 to 2013 returned to having a more connected character than even in 1880. The distribution of built form sizes also reverses and large buildings gain a larger share of the proportion of the built form, again reverting to 1880 proportions. The change in the trajectory of growth illustrates that at different points in the urbanisation process different priorities for development are balanced. In the earlier period there was the drive for rapid residential expansion on the fringes of the city, fuelled by intertwined social and commercial concerns. Once this had been achieved the development trajectory switched towards creating a more urban topology to the network and more evenly distributed range of built form sizes serving different purposes. The development of a greater proportion of larger buildings at the end of the 20th Century as shown in figure 3, can be understood in the context of the changing structures of centrality shown in figure 4. The structure of the distribution of choice changes over time up until 2013 when there is a secondary distribution of the highest values with a separate peak of values. This secondary distribution is indicative of the foreground network (Hillier, 1986) acting as a separate network structure overlaid on the background network of lower choice value routes throughout the street network. The concept of the foreground network can also be applied to the built form in understanding it spatial and social functioning within the city. The larger building can be understood as the foreground of built form that sits apart from the background of smaller residential buildings. An examination of the historical development shows that as the foreground network differentiates itself, so does the built form through the development of large buildings. Whilst the theory of the foreground and background network conveys the layered structure of city street networks, a combined understanding of the foreground and background structure that exist in the built form further develops this idea and opens the possibility for understanding the ways in which these structures within the network, augmented by the buildings that surround it, exacerbating the differentiation between foreground and background structures within the urban system

The implications of these observed phenomenon in the changing structure of the network and built form is that, viewed at the system level, there is a reversal occurring to the structure of the urban fabric away from the highly disconnected and residential urban form that developed at the beginning of the 20th century, bringing about a reversal of the previous domination of residential buildings and dead-ends within the network. The fringe areas of the city can be seen to be developing over time towards a more connected topology and diverse built form composition once the initial residentially led expansion has taken place, moving away from the morphological forms of the stereotyped suburban landscape.

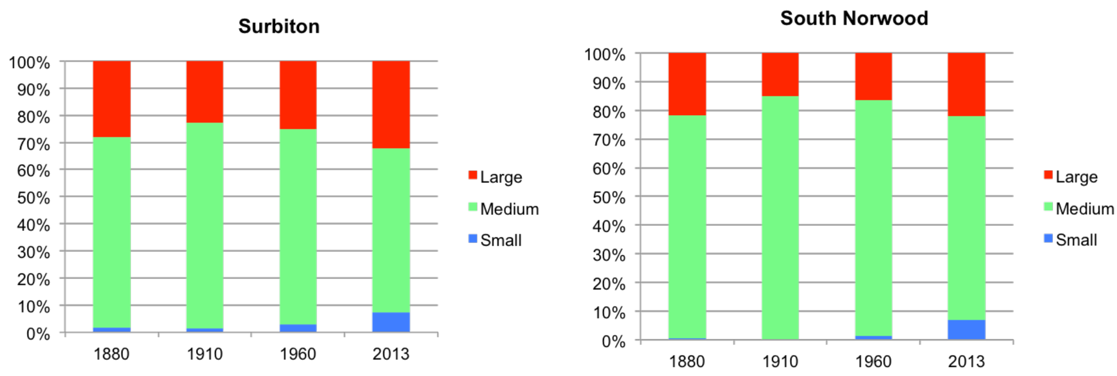


Figure 3 Changing composition of building footprint sizes

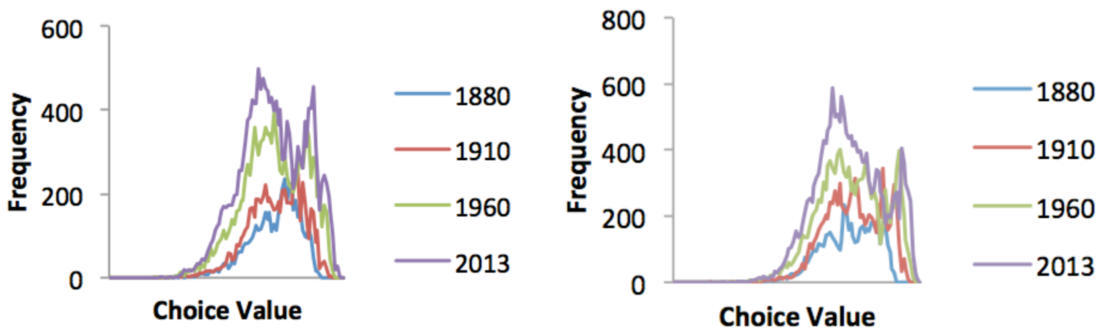


Figure 4 Distribution of Choice values radius 3000m for Surbiton (left) and South Norwood (right)

Whilst the above discussion highlights certain fluctuating metrics of urban form over time, there is one relationship in the evolution that showed a clear and sustained trajectory. This was the relationship between the street network length and the total built area. In figure 5 the graphs illustrating this relationship show that along its length the network is capable of sustaining increasing large loads of buildings being attached to it, whilst not increasing in length at the same proportion. This capacity of the street network to accommodate an increasingly large area of built form suggests a way in which the potential for urban development is embedded within the pre-existing structures of the street network. It is also highly suggestive of the need to have a clear understanding of the morphological structure of street networks when they are being planned, in order to ensure that they are laid out in such a way, as to not preclude potential future developmental trajectories. Furthermore, it shows the enormous capacity and redundancy, built into the urban system for development of urban areas beyond what they are today without having to implement extensive new street systems. The notion of suburbia being synonymous with sprawl (Brueckner, 2000) has been shown here to not be the case in the context of London's peri-urban growth. Whilst the network has expanded to cover a larger area the rate of building densification has greatly exceeded the network growth, indicating that more than sprawling the peripheral has in fact predominantly increased in density in response to increasing urban growth pressures. This highlights the adaptability of the street network systems to future development that could not have been foreseen at the time they were constructed.

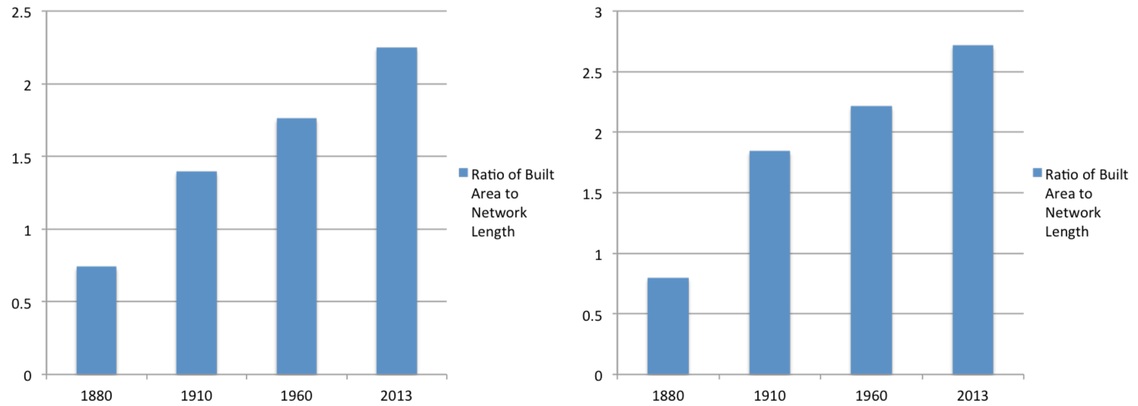


Figure 5 Ratio of built area to network length across time periods. Surbiton left, South Norwood right

The historical evaluation of the relationship between the built form and network development shows that they co-evolved in the peri-urban areas that have been analysed, bringing about specific forms of growth within the urban fabric at different times. The initial drive for residential expansion occurred as railway infrastructures developed, and the separation of residencies from places of work gathered pace, bringing about a rapid change in the urban morphology. This then reversed over time and the areas began to develop a more urban character, by both the structuring of the network and mix of building sizes. The present day situation of the town centres in regards to their network centrality explored in chapter 6 showed that the differentiating factor between the core and periphery of London is how their network centrality within the overall street network changes across scales of measurement. Whilst at the local scales, centres in the core of London and the peripheral case studies share very similar choice and integration values, as the scale of analysis is increased, the peripheral and central areas diverge in regards to integration. The central areas having consistently, significantly higher values, with the exception of South Norwood that occupies a middle ground between core and periphery. However, all the centres, both central and peripheral, share similar values of choice across all scales, as shown in figure 5. Whilst the historical analysis shows that the peripheral areas have moved towards a more urban form, away from the residentially dominated disconnected network, the primary difference is in their proximity within the network to all other origins and destinations. The similarity in choice values shows that they are on routes through the network that have the potential to generate similar through-movement, but they are far less likely to be destinations within the overall network, defining them as relatively peripheral (with the exception of South Norwood), within the system of the street network of London as it is today. Importantly, as the example of South Norwood demonstrates, these peripheral areas are in a constant state of change, and changing trajectories, therefore attributing a finite label to them fails to acknowledge the future character and relationship to the urban areas they may have in the future.

The contested nature of the image of suburbia, that pervades discourses surrounding it, often framing it within negative stereotypes and clichés (Vaughan et al., 2009; Vaughan et al., 2010) has been shown to not be generically applicable. The peri-urban is not a fixed entity that can be generically labelled, but a rapidly fluctuating and evolving part of the urban fabric. Furthermore the aspects of suburbia that are often framed as negative aspects; such as residential dominance are products of wider city-scale processes relating to space and mobility. The complex development of different network structures serving different purposes, and fluctuating built form make-up illustrate that within areas considered to be generically suburban there is a diversity and multiplicity of urban forms such that these areas cannot be simply or easily classified. Furthermore the analysis showed that these areas are in engaged in a constant process of change that is non-linear, illustrating the engagement of the periphery in the continual city-building process. Whilst there are commonalities in the historical development and present day forms across the four case studies, these are more suitably characterised as the forms associated with the process of urban expansion generally, and shifting modes of relation between the continuum of urban fabric between the urban and rural, rather than an intrinsic aspect of peripheral areas, of and unto themselves.

Figure 6 Choice and integration values of town centre case studies in relation to centres within the core at 10,000m analysis radius

8.4 Macro and micro scale infrastructural interventions: bypasses, orbitals and local centres

The development of the network topology and the built form composition show different stages of development in the peri-urban areas at the fine grain scale of the overall composition of the urban fabric, but large changes have also taken place. When moving from the fine aggregated scale to the large-scale, macro scale interventions and developments of the street network system are evident. These interventions are seen in three of the four case study areas: High Barnet, Loughton and Surbiton. To the north of High Barnet and Loughton between 1960 and 2013 the M25 orbital motorway is constructed, and in Kingston between the 1910 and 2013 time periods the Kingston By-Pass is constructed and augmented. Whilst these large-scale changes have occurred, smaller changes have also been observed to have taken place in the case study areas, transforming the spatial relationships between local centres. The changing configurations and centrality at these scales addresses the question relating to the changing structures of centrality across scales on the periphery of the city.

The construction of motorways and other large-scale road infrastructure around the world that began in the 1920's and 30's can be traced back to the United States, and later Italy and Germany. The first motorway-type infrastructure, termed Park-Way, was the Long Island Motor Parkway in the United States, opened in 1908. This was a private venture advertised as a leisure attraction, where people could drive along a large road surrounded by idealised rural landscapes (Kroplick, 2008). The first publicly accessible park-way opened in the 1920's. The later development in motorway-type infrastructures came in Italy in 1925 and then in Germany in 1932. The development of the road infrastructures in Italy and Germany are often understood in terms of national identity and nation building through the creation of grand projects that spatially unify a region or country, and are often justified in terms of economic or social benefits (Merriman, 2009). Britain was late to adopt the practice of motorway construction with the M1 opening in 1958, but prior to this some large road infrastructures were already in place. A major catalyst for the building of orbital ring roads and by-passes was the highly influential Traffic in Towns (Buchannan, 1963) report commissioned by the Ministry of Transport that suggested that the impending explosion in car ownership necessitated protecting town centres from over-congestion. One proposed solution to this was to construct road infrastructures such as by-passes and orbital motorways.

One of these early large road projects was the Kingston By-Pass that was opened in 1927. In figure 7 the present day junction of the Kingston By-Pass is highlighted on a map showing integration at radius 3000m. From this map it is can be seen that the junction of the By-Pass forms an important feature within the centrality of the area, structuring the potential for movements within the area, indicating the impact that the construction of this infrastructure has had on the area. Below this map are four close-up maps of the highlighted junction, one from each of the time periods that the areas was analysed for, showing the detail of the changes that took place. In 1880 there is simply a kink in a small road, the same is present in 1910 and then by 1960 the original multi-lane By-Pass that was opened in 1927 has been constructed (figure 9). This is further developed by 2013 where multiple levels have been introduced and the road has undergone further widening. Figure 9 shows aerial images from 1928 of the newly constructed By-Pass. In figure 8 a comparison between two views of the junction from figure 7 in the 1950's and 2013 are shown. This view from the ground highlights the changes that have taken place between these periods in relation to how they affect the lived experience of the local area at ground level. In 1960 all the junction's structure is at the level of the street, with pedestrian crossing provision. However, by 2013 the infrastructure is primarily designed for the car, and pedestrian pathways are structured beneath the roundabout via suspended walkways.

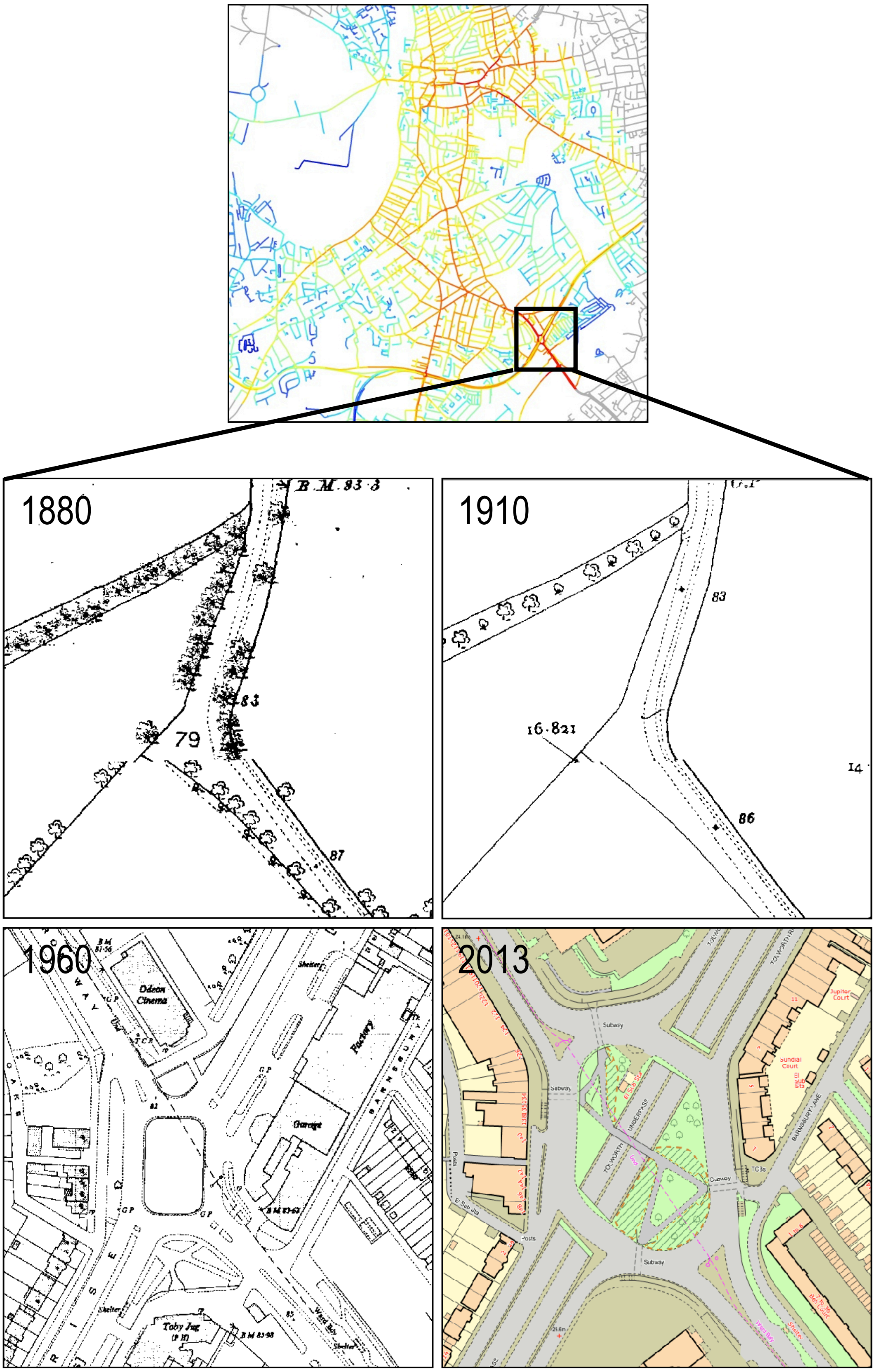


Figure 7 Transformation of Kingston By-Pass junction in Surbiton study area

Figure 8 Transformation on the ground of the Kingston By-Pass junction. Top image c.1950s, bottom image 2013

Figure 9 First section of the Kingston By-Pass is opened to the public in 1927. Copyright English Heritage

The second example that occurs in the case study areas is that of the M25. In figure 10 the M25 in 2013 is highlighted on the northern edge of the High Barnet and Loughton case study areas with an image below showing the construction process of one section of the M25. The M25 orbital motorway has its origin in the 1937 in The Highways Development Survey (Bressey and Lutyens, 1937) and later Patrick Abercrombie's 1943 County of London Plan and the 1944 Greater London Plan, where a series of orbital motorways at different distances around the capital were proposed. These proposals came at a time of a drive towards modernisation. It was thought that, through the construction of orbital motorways, flows of traffic around and through London could be rationalised, creating efficiencies of speed and movement, that would allow the modern city to emerge, freeing it from the constraints of its ageing and congested road infrastructures. The construction of the M25 only began in 1973. The complete M25 orbital motorway was opened in 1986, by the then Prime Minister Margaret Thatcher. In the case of the M25 it was built on land that was previously unoccupied by roads, and required compulsory purchase order to compel landowners to sell their land in the locations where the motorway was to be built.

In the context of peri-urban development that this research focuses on, these large-scale road infrastructures form part of an important dynamic between the periphery and the core. Fringe areas of cities are often characterised by the awkward confluence of different scales and seemingly contradictory uses (Garreau, 2011), the coming together of distribution centres, industrial parks and residential areas, criss-crossed by local roads and remnants of a rural past, with the elevated, multi-lane motorways passing through the areas, paying little attention to their historic, local structure, that had developed for centuries and gradually adapted to the advent of new mobility technologies, enabling faster access to the core of the urban area (Sheller and Urry, 2000). In the case studies that were analysed some of the typical urban-fringe features are present: the large road infrastructures, mixing of land uses and historic road networks embedded within the new infrastructures. The effects of large-scale infrastructure developments of the Kingston By-Pass on the structure of network centrality in Surbiton are significant at radius 3000m of analysis. In contrast to this in both High Barnet and Loughton where the M25 is present on the fringe of the study area, the structures of centrality are not affected to a significant degree. This lack of impact of the M25 on the local morphology indicates that the building of the new road network to serve the city scale is doing just that. It does not integrate with the local network and therefore does not affect the local structures of centrality. The new network is therefore seen to be acting at a larger scale, the scale of the city. This was its intended use in moving traffic around the city, rather than through centres, in order to alleviate issues of congestion. In Surbiton the Kingston By-Pass does have an impact. The by-pass is more closely interlinked with the local network, integrating the configuration of the new with the old. This is also likely due to the gradual evolution of the Kingston By-Pass as shown in figure 5. The gradual development slowly integrated the new network structures into the local grids, whereas the M25 in proximity to Loughton and High Barnet, is rapidly built and did not interact, creating the typical urban-fringe scenario of large scale road infrastructure flowing in proximity to the area, without integrating or referencing the local morphology. The concepts of edge-city (Garreau, 1991, 2011) and the dynamics of the rural-urban interface (Kiel and Shields, 2013) are useful concepts that allow a way into the discourse of the particular features of peri-urban space, but they situate the discussion largely within the spatial confines of the peri-urban area itself. This analysis has shown that in order to understand the peri-urban a wider spatial frame of reference is necessary. The development of new forms of transport, such as trains and automobiles, and road network infrastructures, such as the Kingston By-Pass and M25, are city scale processes that manifest themselves in particular ways on the fringes of the city, therefore to understand the peri-urban, an understanding of city wide development processes, that culminate in what is observed on the periphery is necessary. What is unique to the peri-urban is the ways that infrastructure interact, as shown in the space syntax analysis of the historical development of the street networks across the four case studies. The interaction between city-scale network infrastructures was shown to vary, in some instances integrating with the local street networks, influencing and reshaping the structures of centrality, and in other cases showing minimal interaction and effects on network centrality within the case study localities.

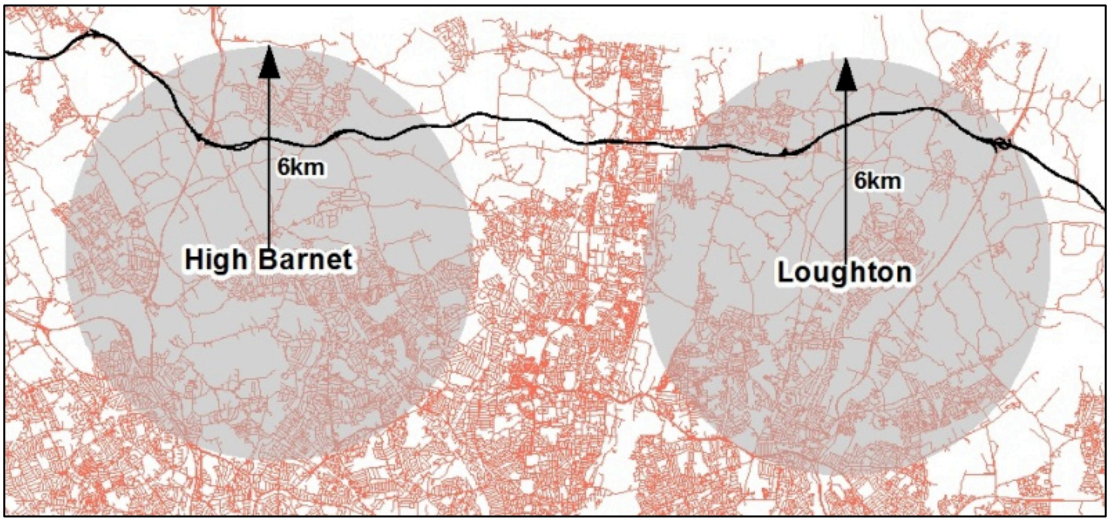


Figure 10 Section of the M25 passing through High Barnet and Loughton study areas (top). Construction of the M25 (bottom)

The hierarchy and relationship between mobility networks serving different purposes within the case study areas is central to understanding the spatial relationship between the case study areas on the periphery and the urban area as a whole. The development of large scale infrastructures, designed with the centre of the urban areas in mind interact in particular forms on the periphery where they are not intended to directly integrate with the local road systems. By understanding the interaction both spatially and historically, between the development of large-scale transport infrastructures and local areas, a better appreciation of the nature of the spatial relationships and hierarchies that exist within in a city can be generated. Furthermore, through spatial analysis of the configuration of these networks a quantitative realisation of these interactions can be gained.

The concept of multiple centrality (Hillier, 2002; 2009) when considered in relation to the historical network analysis can be contributed to in two principal ways from the historical analysis presented in this research. In the case studies, particularly Surbiton and South Norwood, new locations of high choice and integration were shown to emerge at 800m radius of analysis, illustrating the proliferation of centres over time, in line with the theorised multiple centrality structure of the city. It was also shown that over time the relationship between these centres developed such that they came enmeshed in a continuous network of centres at larger radii of analysis. It is proposed that a key feature of cities, and their spatial development process is the changing relationships that exist in the spatial structure across scales over time. That is to say that whilst the configuration of the street network may be composed of multiple centres, as urbanisation occurs the scale and relationships between centres dynamically changes. Alexander’s (1965) proposition that the structure of a city is not tree-like, and that it is a series of nested and overlapping structures working at different scales correlates strongly to the findings of this analysis. Although this analysis shows that the nested structures of centrality continually evolve, and that this can occur unevenly across space, as in the case of South Norwood that showed a very strong divide in the spatial development of the area.

The influence of the pre-existing street network structures on future development has been demonstrated in other urban regions before (Oliveira and Pinho, 2007; Serra and Pinho, 2012) and was confirmed in this analysis. In all the case study areas the network structures that were present in 1880 persisted until the present day and retained their high centrality. Due to network growth occurring around these locations, reinforcing their centrality within the network. This illustrates the path-dependence (Arthur, 1988; Batty 2007) that occurs during urbanisation, influencing future growth patterns and potentials. This in itself highlights the need for considered approaches to drastic urban planning interventions due to the impact it has on potential future developments; this is particularly relevant in rapidly urbanising regions where whole cities are being reshaped. In contrast to the continuing presence and influence of historic network structures, the analysis also showed that there are also radical reshaping of the street network through large-scale interventions, such as the Kingston By-Pass in Surbiton and the M25 in Loughton. These interventions in themselves can create new dynamics within the network, in some cases reshaping the historical structures of centrality. The confluence of the historic and the new in spatial infrastructure terms was found to be a defining feature of the case study areas, highlighting the periphery as a location for synergetic processes of urban development operating at both the local and city scale.

8.5 The emergence of new building typologies and land uses

The development of the street network and its structure has been a central component of this research in its aim of understanding the spatial character of the development of the urban fringe. In the previous section the discussion centred on the development of large road infrastructures in the peri-urban areas, within the context of modernist rationalisation, and ideas around speed and efficiency. These developments had some impacts on the local structures of centrality in the street network within the case study areas, as in the case of Surbiton, but they had negligible impacts due to their detachment from the pre-existing street network systems, in the case of the M25 in Loughton and High Barnet. Whilst these network developments took place on a large scale encompassing the entire city there are more nuanced changes that took place at the scale of the individual dwelling within the case studies, closely linked to these large scale developments in the network.

In chapter 7 the historic built form record was analysed in order to understand the ways in which the composition of the built environment had changed over the course of the study period. The most striking finding in this analysis was that a whole new typology of buildings emerged between 1910 and 2013, shown in figure 11. Further analysis found these buildings to be garages, highlighted in figure 11. The emergence of a whole new category of buildings across such a large dataset of approximately 35,000 individual built features in each case and in each time period, indicates that apart from the overall growth in residential buildings discussed earlier, this is the most important change to the built form over the study period. From this alone it can be said that the garage is a fundamental feature within the history of the built environment of the peri-urban areas of London. There has indeed been extensive discussion of the re-modelling of the suburban landscapes through architectural adaptation and addition, and specifically the development of garages in suburban areas (Clapson, 2003; Whitehand, 1991, 1999, 2001). The affirmation in this research of the importance of the garage through empirical reconstruction of the built environment demonstrates that they were central to the construction of the suburban architectural landscape. Furthermore it adds to the argument of their importance and indicates that the social relationships between the car, home and city, in regards to mobilities is an area that further research should be directed towards.

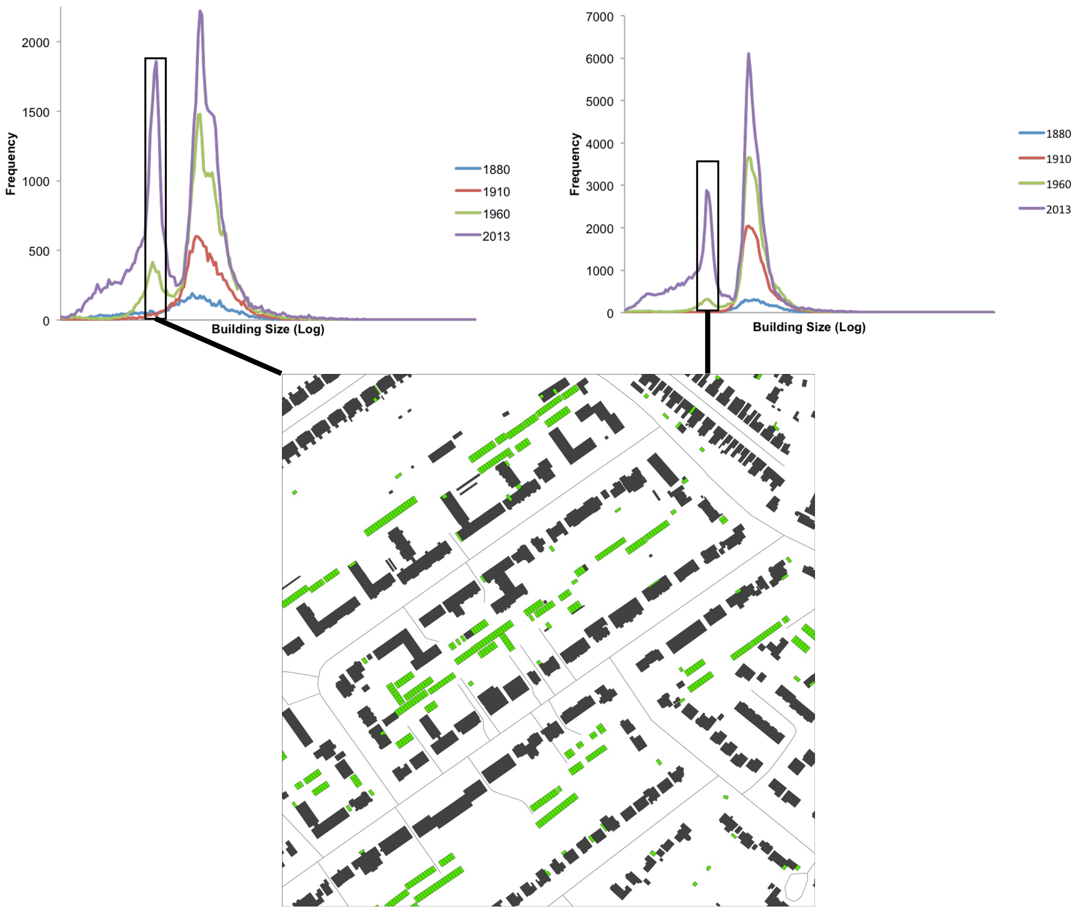


Figure 11 Emergence of the new building typology of the garage. Emergence within built form size distribution (top). Garages highlighted on built form plan (bottom)

In the context of the previous discussion transport can be seen to have played a vital role in the expansion of London into new territories by reducing travel time from home to work, leisure and so on. This has been through the expansion of the rail and Underground network as discussed earlier, and the development of road infrastructures enabling rapid movement through and around the urban area with the aim of increasing road volume and speed. Whilst there is significant credit given the rail and Underground network in enabling this expansion (Jackson, 1978), with the exception of the work of Clapson (1998), much less credit is given to the similar role played by the private motor car in the social and spatial development of London. Although this is of course widely appreciated in studies of the US, Australia and elsewhere (Bullard at al., 2000; Cohen, 2004; Kane et al., 2014). Nevertheless the case has been made quite recently that it was an important aspect in the development of British suburbia in the mid to late 20th Century (Law, 2012). This analysis reinforces this reading of suburban development by empirically demonstrating the role of motorcar adoption in reshaping the architectural forms of suburbia on a large scale.

Returning to the development of the garages as a significant architectural feature within the peri-urban landscape, the relationship between the development of the architectural forms and the actual ownership of motor vehicles reveals a strong correspondence. The chart in figure 12 taken from the Parliamentary report Olympic Britain (2012) shows the number of private cars cumulatively licensed across the UK from 1908 to 2008. In 1960 there were approximately 9.5 million privately licensed vehicles, by 2008 there were 53.5 million. This represents an increase of 5.6x. When the figures for the garage in the overall composition of built forms are examined, normalised for the number of domestic sized buildings in each area, it is found that in Surbiton there is an increase of 4x and in South Norwood an increase of 5.4x, for the period 1960 to 2013.

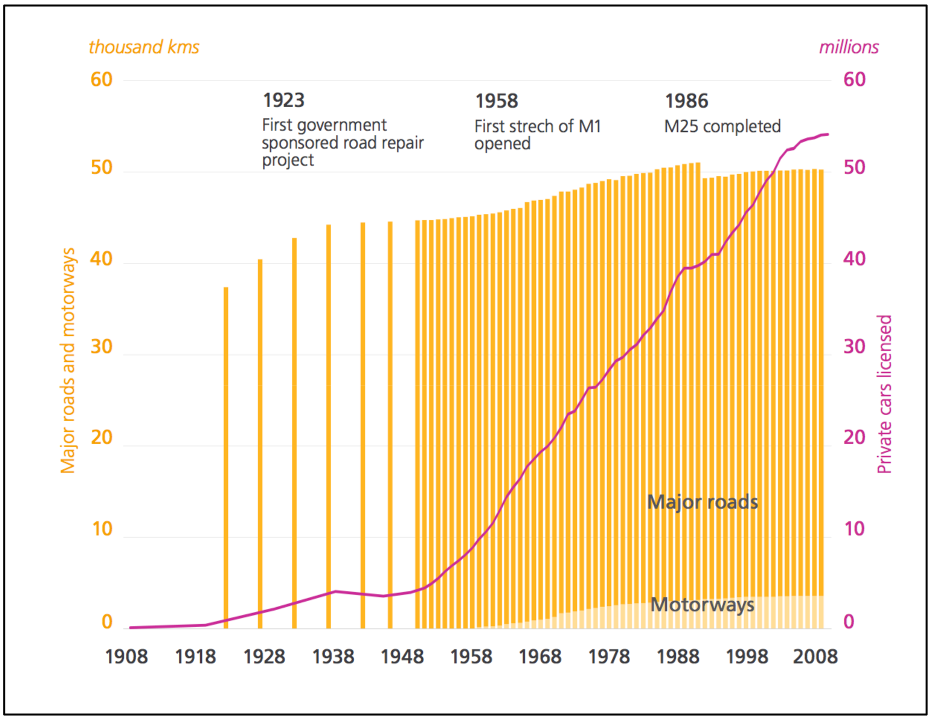


Figure 12 Cumulative numbers of licensed vehicles in Britain 1908-2008. Taken from *Olympic Britain* Parliamentary Report, 2008.

The intertwined story of the development of mobility technologies and peri-urban development has a multiplicity of components, not least the railway systems. Whilst the railways have been linked to the general urban expansion of the periphery (Levinson, 2008), at the 'micro-scale' (Whitehand, 2001) of the individual building, the relationship between the mobility technologies and the development of urban form has not before been empirically measured at such a scale. This analysis has shown that they share a common history, and a discussion of the architectural and morphological development of the urban areas is needed to fully appreciate the importance of mobility technologies, and their individual and collective impact. Whilst this discussion has focused on the railway and road based infrastructure developments on the periphery of the city in the 20th century, other mobility enhancing technologies that predate these also will have had fundamental effects on the development of urban areas. In figure 13 one such example is given. In this figure a section of the same area within the Surbiton study area is highlighted in the periods 1880 and 1910. The highlighted area shows the evolution of the mobility technologies over time within the same location. In the 1880 period the buildings are being used as stables, by 1910 they are no longer stables and a tramway has been built along the adjacent road.

Figure 13 Changing mobility technologies in Surbiton. 1880 (left) highlighting stables. 1910 (right) highlighting tramway.

In the context of a general theory of urban function, referred to as the movement economy (Hillier, 1996; 1997), the development of the urban form around these mobility technologies can be more clearly understood. The configuration of urban space to structure flows through, and to specific locations that enables certain function to occur in specific places will be heightened by technologies that allow more frequent and rapid movement through the city. Businesses and services that are dependant on flows of people through the urban system will benefit from this increased capacity and speed of movement in the city. The decrease in travel times to the centre and the general mobility afforded by new transport technologies enables a far richer and wide ranging structuring of movement around the city to take place, as well as potential homogenisation due to ubiquitous and rapid accessibility to the most central areas, which transport infrastructures are configured around. In figure 13 the highlighted change from stables to tramway in Surbiton, and later garage development show how the affordance of movement for inhabitants of the city have changed, but it is the implications on the ground as seen in the land uses that exemplifies the impacts of these changes. In 1880 and 1910, tailors, boot makers and dressmakers were found on the high street of Surbiton, but these gradually disappear by 1960, to be replaced by department stores and today the dominant emergence of a new kind of space is transforming local centres once again.

The analysis across chapters 5,6 and 7 was sequenced in such as way as to cerate a continuum of increasingly finer resolution to the analysis of the changing urban fabric, from the city scale down to the land uses of individual buildings on the high streets of the Surbiton and South Norwood case study areas. It is the analysis of the land use change over time that revealed both the change and continuity that is found in the centres of these local areas over the past 130 years. The centres were found to have retained their commercial land uses in some form over the entirety of the period, emphasising their continual importance as centres of activity. This highlights continued utility and centrality within the daily lives of the local populations (Vaughan et al., 2009; 2010). These findings reinforce the understanding of the importance of local centres in shaping everyday life through daily routine (Urry, 2007) and co-presence (Southerton, 2006). Furthermore it emphasises that even over a period of 130 years the inherent spatial capital (Marcus, 2007) of these centres has been maintained. Whilst there is this stability to the continual commercial land use in these areas there is also constant change in the particular land uses that occur there. The biggest shift that was observed was the re-orientation towards land uses classified as third space (Oldenburg, 1989) in both case studies over the last 50 years. This land use is characterised by space that can be used for various forms of socialisation or individual pursuits in addition to their commercial function. These spaces are conceptualised as being social productive spaces (Oldenburg, 1997), therefore the observed transformation of local high streets to provide third spaces has important implications for the locations and forms of social interaction that can occur in new types of space in the city, namely the emergence of dynamic urban spaces that have the potential to serve multiple social and economic functions. The emergence of third space within local centres is related to the concept of the creative city and flows of information (Florida, 2005; Landry, 2000). The forms of co-presence that these spaces afford bring about the potential for new understandings that arise from sharing space and interacting with unfamiliar individuals. Technology plays an important role in this new dynamic as the rapid emergence of mobile computing has allowed people to engage in tasks wherever they wish, that might have previously been confined to the home or workplace, in some ways overcoming the previous spatial confines associated with certain daily routines (Graham and Marvin, 1996) and creating new spatial dynamics of those routines. Furthermore these new technologies have allowed new spatial dynamics of retailing and consumption to occur that would have been confined to the traditional shopping street in the past. These locations have now been observed to be re-orientating towards these third space uses.

As new mobility technologies are developed, increasing flows of movement through and within the urban system are enabled. The concurrent changes in land use that were observed also show how the potential for particular forms of co-presence are enhanced, enabling greater potential for direct and indirect exchanges between people (Jacobs, 1961) to arise, in both their economic and social capacity. It is through the potential for interaction brought about by the development of new forms of shared space, and the co-evolution of mobility technologies, built forms and infrastructures, produced by social and economic developments and dynamics, that the city constantly creates and re-creates itself. The results of the analysis suggest that this enables continued urban development to successfully take place and urban areas to remain at the centre of contemporary human civilization, through the constant enhancement of the potential for movement and exchange to take place , reinforcing and enhancing the spatial capital (Marcus, 2010) of the city.

The emergence of garages as a new typology of building, in both Surbiton and South Norwood illustrates the changing relationships over time between mobility, technology and the built environment. The notion of mobility as a driver for society and its products (Urry, 2002; 2007) is shown in the analysis to be apparent in the architectural forms that are produced in particular periods. Whilst significant changes have been shown to occur, alongside this there are invariants in the urban fabric and its use. The town centres still persist as locations for activity, albeit changing activities, and the places still exist as identifiable places within the expanded and urbanising city region. The duality of change and invariance that can be seen across all facets of the analysis that has been presented indicates that in understanding urban spatial and social development that which does not change, is as important as any changes that can be observed. In discussions about the impact of technology on urban life, and society more generally (Graham and Marvin, 1996) this duality has to be borne in mind.

Specifically in this analysis change is observed to have occurred in uses of the high street, whilst the high street as a space of utility to the local areas continues; the street network develops and new structures that do not reference the existing network are superimposed, whilst the original network remains; new forms of buildings appear and the distribution of building sizes fluctuates over time, eventually reverting to a distribution akin to the earliest period of analysis, whilst the majority of buildings from the earliest period remain and their functions persist. The relationship between continuity and change is central to all the processes that are observed in this research, and it is proposed are central to understanding not only the evolution of the urban fabric, but the society that inhabit it.

8.6 Bringing together methodological approaches and data representations

Chapter 4 presented the analysis and evaluation of the differing street network representations for use in space syntax analysis and also developed the methodological approaches to historical data capture that were used to produce the historical built form data that was analysed in chapter 7. The combination of the historical GIS data capture methods and street network reconstruction techniques overcame the primary barriers that exist to historical geospatial research, of data interoperability and availability (Southall, 2013; Gregory and Healey, 2007). This facilitated the construction of a representation of the street network and built features across all the time periods of analysis. The development of the method to reconstruct the built form record is particularly important as it brought together software solutions and approaches from a range of specific applications in order to enable faster and more wide ranging historical urban scholarship. Data representation is fundamental to carrying out effective analysis due to the fact that the analytical outcomes are contingent upon the properties of the data the analysis is carried out on (Kwan et al., 2003). Through the solutions employed in this research a unified data model across all time periods was created that satisfied this criteria whilst ensuring it was not so specific as to limit the methodology and output to a narrow range of applications. Within the space syntax research field representation and abstraction of space through data structures is particularly relevant, as the analysis relies upon the angular relationships between street sections in order to calculate the centrality of a street within the network. The axial representation of the angularity of a street network relies upon the angular relationship that exists between accessible convex spaces, rather than the angularity of the connections between the centre of a space, as is the case in road centre-line network representations, such as Ordnance Survey and Open Street Map street networks, that were evaluated in comparison to the axial model. The analysis that was presented of different street network representations confirmed the findings of Turner (2007), that road centre line models, when subject to angular segment analysis demonstrate the same properties as axial representations.

This comparison was technically explored, but irrespective of the technical aspects of the representation there is a philosophical question that has be addressed first, relating to the fundamental understanding of what city space is, and how that understood reality is best represented. The axial representation of city space that creates the minimal network to provide visibility to all areas of a convex space, in this case the continuous space of the street bounded by buildings, is suggested to have a stronger relation to the internal cognitive representation of the inhabitants of the space it aims to represents (Hiller and Penn, 2003). This relationship can be understood to be a shorthand representation for the perceived landscape of space that affords possible routes through the network. This is the dominant representation that is used in space syntax research, but road centre line network representations have been shown to be capable of capturing the probability of movement to an equal or greater degree than axial representations, when analysed using segment length weighted angular segment analysis (Turner, 2007), and furthermore they were shown in this research to fundamentally represent the same geometric and topological structures in the city. This research found that the defining difference between the representations was in fact the detail, and indeed, the range of values across all centrality metrics increased when road centre-line network representations were used. This increase in the resolution of the network analysis reduces the level of abstraction (Goodchild et al., 2007) permitting a more spatially nuanced analysis of street network configuration. The analysis demonstrated that although there may be philosophical underpinnings to the choice of certain representations, these choices have to be made through rigorous data analysis and comparison to validate any theoretical position in relation to representation. Especially when alternative data sources that are more readily available and interoperable with other geospatial data can achieve the same, or better results, yet may not conform to theoretical positions.

8.7 The intersection of networks, buildings, land use and mobility infrastructures

Methodological approaches are key to enabling new research to be undertaken that pushes forward research domains through the integration of approaches and tools from a range of research areas. In this research the integration of approaches from GIS historical geography and morphological research have been brought together to enable research to be carried out that has been able to reconstruct the physical urban past in detail and scale to interrogate the general and specific evolution of peri-urban London over 130 years. Furthermore through testing and evaluating spatial representations of urban space better understanding and interoperability between the representations used in different disciplines can be achieved.

The development of the peri-urban areas has not been one of continuous trend or smooth trajectories. Underlying these general trends are fine-scale shifts in trajectories that highlight the changing social reality and drivers for their development that have taken place at key moments in time. The primary feature of the peri-urban cases studies has been one of residential development of domestic buildings, but over time this trend has shifted towards one of more balanced composition of built form, balancing the residential built forms with those of other uses. Furthermore after the early stages of residential expansion the network gained a disconnected character synonymous with the suburban cul-de-sac, but this also reversed over the remainder of the study period as urbanisation continued, and the network became more connected over time, again reversing its initial trajectory of development. Whilst this indicates a fluctuating trend, the process of urbanisation has continued steadily with increasing built area populating the study areas. This has been at a rate far greater, proportionally, than the growth of the network. This pattern of growth shows that London’s street network has an embedded capacity for compact densification of its street network without the need for sprawling expansion. It is likely that this will be the case in other cities currently struggling with rapid growth.

A key feature of the case studies has been the emergence of large-scale orbital roads and by-passes. These infrastructures of motor vehicle based mobilities have reshaped the landscape of the periphery of London. The motorway developments have a significant history intertwined with social and economic ideas about city and how it does, and should function. In relation to the spatial impacts of these networks, in some cases they do interact with the local grids through gradual integration and development, although the rapidly developed networks often do not reference or interact with the historic structure of the local areas. Importantly the experience on the ground of interacting with these infrastructures has changed dramatically as their scale has increased, likely having significant social impacts.

At the scale of the large new road based infrastructures there are obvious and widely discussed impacts, at the scale of the individual building small, incremental changes take place that are themselves linked directly to processes driving the larger scale developments. The development of new architectural forms in the emergence of garages in the peri-urban case studies illustrated this. The development of the garages closely matched the uptake in car ownership and the time periods when the large-scale road building took place. These developments of urban areas, linked to the history of mobility technology, highlight how the city has successfully functioned and developed over time. The combination of the railway system, road and vehicle infrastructures enables new and constantly evolving mobilities in the city. The constant development of new forms of mobilities linked to the changing urban form and spatial network structures, illustrates the interdependent relationships between movement and the city. It is through these technologies of mobility that cities can successfully grow, both in density and area. These findings suggest that the exchanges and externalities that are enabled through ever-greater movement, and thus the movement economy, lie at the heart of the success of cities at adapting, and bringing about, changing social and spatial realities.

9 Conclusion

Cities are in a constant state of flux, constantly changing in both their physical and social capacities. Creating positive urban futures is reliant on understanding the relationships between people and the spaces that they inhabit, and how they make and remake one another.

This research has shown the spatial and architectural development of the periphery of the London urban area that has taken place over the last 130 years. Whilst no account can be complete in all aspects, this research has demonstrated as comprehensively as possible the spatial and architectural stages and forms through which peri-urban London has developed, from the urban to the building scale. Through the application of rigorous data approaches and novel methods, this historical account of the urban development has been able to reinforce pre-existing work and theories as well as empirically advance our understanding of the stages and processes of urbanisation. The finding that the growth of the built mass greatly exceeded the network growth in all periods demonstrates a crucial aspect of peri-urban development, namely the redundant capacity within the network to absorb increasing density of buildings and therefore population. This acts as a counter to the sprawl arguments often levelled at the periphery of cities. It also highlights the inherent potential in the street network, that if properly understood can be used to effectively densify peripheral areas by working with the grain of the spatial ordering that is already in place. The importance of the layout of street systems is therefore paramount, as it has been shown to form the basis of future spatial orderings. This highlights the importance of urban planning that is not finite in its outlook, to ensure spatial sustainability through planning that acknowledges the necessity of adaptability in a constantly changing urban system. Furthermore this research highlights the intrinsic adaptability of historic street network systems to new social and spatial realties that have emerged over 130 years.

A key theme across the findings from the analysis and discussion was the constantly changing nature of the peripheral areas, seen through their configurational and built form attributes. Whilst there were common developmental trajectories, such as greater built form density and network growth, these general trends contained nuanced and fluctuating variations over time and space, including the composition of the built form, network character and the configurational variation across small areas. These constant variations over time and space illustrate the fallacy of finite and conclusive labels being given to peripheral areas. In doing this, it fails to acknowledge the history and future potential of these spaces to evolve over time. Rather than labelling them as simply suburban or peripheral an understanding of the local historical properties and spatial relationships with the wider urban area, would allow for a clearer characterisation and understanding of what places actually were, are and could become.

The relationship between the peripheral case studies and city-wide urban development processes were highlighted in the space syntax network analysis. The impact on the centrality of local networks, caused by the development of by-passes and orbital roads was shown to be extensive, although the spatial repercussions of their emergence were seen to be uneven across space in terms of the degree of impact. This was mediated by local variations in the spatial interaction between these new infrastructures, and the pre-existing historic street networks. This illustrated the co-existence of both continuity and change in the urban fabric. The confluence of these large-scale network infrastructures with local networks highlights the necessity of configurational analysis to understand how these forms of development will interact with areas that they traverse or pass in close proximity to. This approach can allow more cohesive and functional spatial planning, that is mindful of the historic structure and functioning of the city, whilst enabling urban development to take place. This is particularly important when, as has been shown, the historic structure is highly adaptable and central for the future development potentials of urban spaces.

The importance of movement technologies in the spatial and architectural development of the urban periphery reinforced the theories of the movement economy (Hillier, 1996), that suggest the flow of people through the urban system is paramount to their functioning and success. Whilst in London the railway system has been shown to have a significant impact on historical urban development patterns (Levinson, 2008), this research has shown that the car, and the infrastructures of both the street network and built forms associated with it, have played a significant role in the forms of urbanisation seen in peri-urban London. All these technologies of mobility develop around the aim of allowing movement to occur more freely, quickly and easily across larger areas. This research suggests that a prerequisite for the movement economy’s contribution to city function is that these technologies are developed and taken up. The continual development of greater mobility, brought about by technological change, allows the city to continue to grow and function as a place of economic and social exchange by increasing the co-presence afforded by greater flows through and to locations in the urban area, and beyond. The emergence of the new typology of buildings in the forms of garages in conjunction with the development of large-scale transport infrastructures succinctly illustrates the social and spatial dependencies that exist between mobility technologies, the home and the city. The arrival of personal mobility technologies was shown to alter the built form of residential space, whilst infrastructural developments took place that facilitated and worked in concert with new mobility technologies. This finding highlights the paramount importance of mobility to city function. The intricate relationships that exist between these factors demonstrates the necessity of understanding the role and methods of achieving mobility in the city, and also the impacts and linkages between the factors that contribute to achieving certain forms of mobility. The impacts on socio-spatial dynamics that these changes in mobility bring about is an important area that needs further research to enable an understanding of the particular socialities that different mobilities engender.

The transformation and persistence of the local centres in the two areas that were subject to further analysis (Surbiton and South Norwood) emphasised the duality of change and continuity that is found in the case study areas and society more generally. The locations where commercial activity was found to take place persisted over the entire 130-year period of analysis, whilst the uses that occurred within them were found to change. The emergence of third space land uses indicated that in the face of changing patterns of consumption, commercial spaces were transforming into spaces that were not defined in terms of retail-based utility, but provided flexible spaces, orientated around social interaction and exchange defined by those who choose to use the space for their particular purposes. When considered in relation to the findings of transformation in regards to mobilities we can see a heightening potential for exchange and movement across multiple spatial and architectural forms in the city, demonstrating the centrality of exchange and movement to the function of urban society. Whilst there is the heightening of the mobility and exchange potentials, many spatial forms and structures of the city are seen to persist across time. This duality between change and persistence is a central consideration that must be made in understanding how society functions and evolves, particularly at the junctures of interaction between the old and the new, when examined spatially, architecturally and socially.

The strong relationship between the street network, the built form and changing technologies of mobility that this research has uncovered suggests that future research could usefully be directed towards understanding the interdependencies between these factors. This would allow the concept of the movement economy and personal mobilities to be more fully understood and planned for within urban development, being mindful of the impacts on the inhabitants of urban areas of uneven development, limiting mobilities for certain groups. Furthermore, future urban research should aim to look at a range of spatial and architectural scales, since this research demonstrated that there are linkages in developmental trends and patterns, from the building to the city scale. These relationships and trends have the potential to reveal the underlying patterns of urban development, and are vital for understanding our urban present as well as future.

The scale and detail of this study joined with a particular focus on the temporal evolution of urban structure has not been completed before for the London region, therefore it forms a contribution to knowledge. Through the multi-scalar analysis of the built form and network structures of peri-urban London an understanding of the city development process has been created that allows new insight into the question of how the fringes of cities develop spatially over time and across industrial and technological revolutions. Through the comparative analysis of four suburban areas the commonalities and complexities in their development within the same city-region was charted, which enabled the development of a rich account of their nuanced spatial and relational development over time.

Through the longitudinal analysis of the change in the urban form of London, one important aspect that was analysed was the structures that are altered, appear or disappear between periods. Rather than simply analysing a particular historical state, this research enabled an understanding of the specific spatial changes that took place and situated these is the socio-technical processes and demands of specific periods and places. Understanding the components of change is in some respects more important that understanding the static historical states, as they reflect the fluctuating nature of urban society and the constant making and re-making of urban space. The research also contributes to furthering the theoretical understating of the logic of urban spatial and architectural development; extending and adding to current ideas about urban network centrality and human interaction within the built environment. This is particularly in relation to the urban fringe and its relationship the wider city development process. This also formed a contribution to the Adaptable Suburbs project through helping to develop a greater understanding of the changing role and structure of suburbs through time in the urban assemblage. Furthermore this work contributes to the space syntax research field as a whole through the development of new analytical techniques and ideas, by bringing together GIS and morphological analysis perspectives and approaches.

Whilst contributing to an understanding of urban development, the focus on research methods and techniques also forms a significant contribution to future research in providing new methodologies for historical urban research. This includes the potential to use road centre line networks as an alternative to axial representations whilst still representing the spatial reality of the city as perceived from the perspective of individuals navigating the geometry of the city. Importantly, it was demonstrated that whilst the form of representation is important in considering the outcomes of any analysis, it is likely that the geometry of the connectivity between spaces is the most important aspect of the network representation of urban space in space syntax research. A deeper focus on the precise geometry of the potential paths of movement is therefore likely to be a fruitful avenue through which to refine network representations used in space syntax research.

The evaluation of the network representations that were suitable for the space syntax analysis and historical street network reconstruction brought together the perspectives of GIS and urban morphological research disciplines by comparing approaches to data representation and analysis. The methods that were used in the reconstruction of chronologies of the built urban form aimed to augment the traditional practice of historical geographic research with the latest capabilities of GIS. This was achieved by using the approach developed specifically for this piece of research for the reconstruction of historic building footprints from historic mapping. By integrating automated and manual techniques to extract the building footprint from historic mapping, the analysis was able to capture the changing composition of the built environment over a period of 130 years across a wide and differentiated landscape. This is something that has not been done before at this level of detail or over such a long time period, enabling new insights into the process of urbanisation. Research is often conducted in relative isolation from other research domains; this has the potential to create barriers to the transfer of knowledge. By understanding the areas of overlap between research areas and the capabilities that have, or are being developed in other research areas, new methods can be developed that enhance methodological approaches to research, such as in this case enabling a scale of research that, without bringing together methods from multiple disciplines would not have been possible. The research that is enabled through cross-disciplinary methods allows new questions to be explored that would not have been possible before.

This research has attempted to enable a greater understanding of spatial, architectural and social development in the peri-urban area of London. It has also attempted to further historical data creation and morphological research approaches through methodological development. Whilst it has achieved these aims to a large degree, multiple areas of inquiry that arise from the findings of this research necessitate further investigation.

Expanding the spatial and temporal extent of the street network and built form reconstruction would be of very useful to understand the overall spatial patterns to the development of city. It would also allow insight into the co-development of land uses and architectural forms of specific periods, since different parts of the city would have developed at different times and would have specific buildings associated with them. This is particularly relevant to the period before and during the development of railway systems, and would reveal the specific spatial and architectural impact of railway development. For example, mobility technologies that came before the railways, such as horses, known to be associated with the specific architectural form of the mews building. Through an investigation expanded in spatial and temporal aspects the relationship between spatial structure, architecture and mobility technologies would be more fully accounted for. Furthermore a greater account of the duality of change and invariance in urban space would be possible. This possible further research would be ideally supplemented by detailed research into the forms and reasons for people's movement in the city and how this has changed over time. Research of this kind would allow insight into the particulars of mobilities in specific periods that would be able to supplement and inform the analysis of the changing urban fabric. One aspect of this that would be highly informative would be the locations of where people work and how this has changed over time. This would greatly inform debates about the economic relationship between the periphery and centre, particularly in understanding the changing relationship between the home and places of production, and how this has affected understandings of socio-spatial relations in the urban assemblage.

The research on land use change suggested that detailed historical and contemporary research into the forms of socialisation that take place in specific places, and how this has changed over time would be of great benefit to understanding how spaces of potential for social interaction have developed, and the social implications of these developments. In relation to the findings of the impact of major infrastructural projects on local peripheral areas, a useful avenue of future research would be to construct a detailed planning and social history of specific infrastructure projects. This would allow an understanding of the debates and reasoning at the time of their inception and construction. They could then be subject to an evaluation of their performance, and whether they have fulfilled the planned design outcome that were put forward during their development. Furthermore it would allow insight into the social dimensions of their development and perceived and actual impacts on local communities.

An area of future work that would be of great benefit to historical spatial research would be the development of data resources in formats that allows comparative analysis with contemporary data. The time and cost that is required to generate the data so that it can be analysed is prohibitive in many circumstance, therefore the development of a national project to establish the availability of historical spatial data in usable formats would greatly aid historical urban spatial research. This would enable a far richer understanding of urban development processes that could inform future planning through an analytical understanding of the development of urban space.

It is hoped this research will have practical implications beyond the academic realm and will allow a greater understanding of how the process of urban design and planning impact on urban space, and how this impact can be made as sustainable and socially positive as possible, whilst being adaptable to allow for the changes that cities will inevitably have to accommodate in the future. This will be of value in both the academic realm and the commercial realm where decisions are made on our urban futures every day. This will be achieved through a heightened understating of how the urban form structures social relational possibilities and the importance of understanding how spatial relationships operate across scales. Furthermore, the historic reconstruction of the street networks and built form records will be a contribution to knowledge through the creation and availability of the data sets to other researchers who will be able to utilise them for their own studies.

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Appendix

List of publications:

Dhanani A., Vaughan L., Ellul C., and Griffiths S. (2012) "From the Axial Line to the Walked Line: Evaluating the Utility of Commercial and User-Generated Street Network Datasets' in Space Syntax Analysis". In *Proceedings of the 8th International Space Syntax Symposium*, Santiago, Chile. Eds. Greene M., José Reyes and Andrea Castro.

Dhanani, A. and Vaughan L. (2013) "A porous urban fabric: the structures and scales of London's peri-urban development from 1880 to 2013". 9th International Space Syntax Symposium, South Korea, Sejong University Press.

Griffiths S., Dhanani A., Ellul, C., Haklay, M., Jeevendrampillai, D., Nikolova, N., Rickles, P., Vaughan, L (2013) "Using space syntax and historical land-use data to interrogate narratives of high street 'decline' in two Greater London suburbs". 9th International Space Syntax Symposium, South Korea, Sejong University Press.

Vaughan, L., Dhanani, A. and Griffiths, S. (2013) "Beyond the suburban high street cliché - A study of adaptation to change in London's street network: 1880-2013". Journal of Space Syntax, 4(2), 221-241.

Jeevendrampillai, D. and Dhanani, A. (2015) (forthcoming) "Making Space: Multi-disciplinary methods for research in suburban spaces." in Spatial Cultures: new perspectives on the spatial morphology of cities past and present' Edited by. Griffiths, S and Von Lunen, A. London: Ashgate Publishing.

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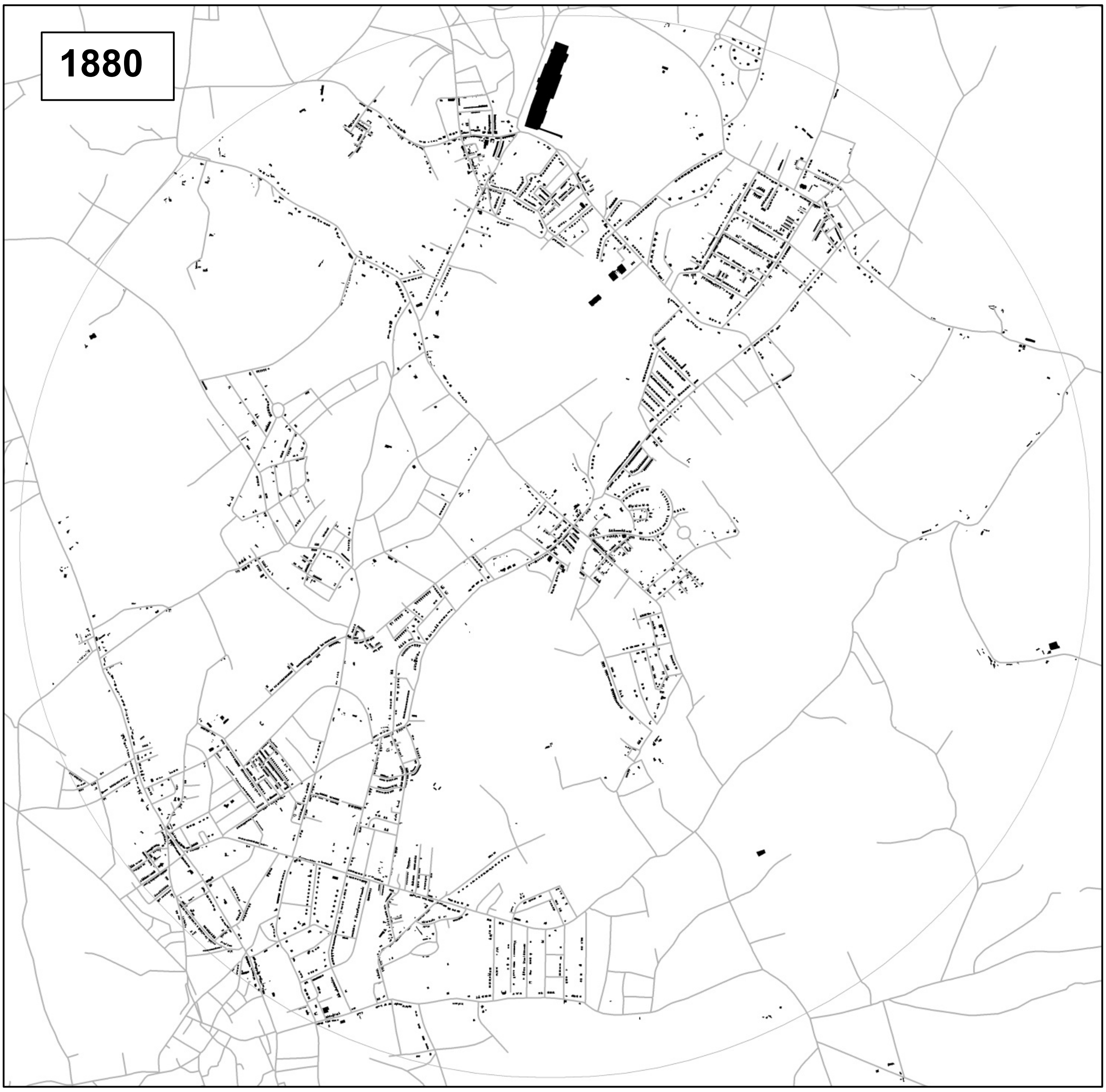
South Norwood Building Footprint Reconstruction and Historic Street Network

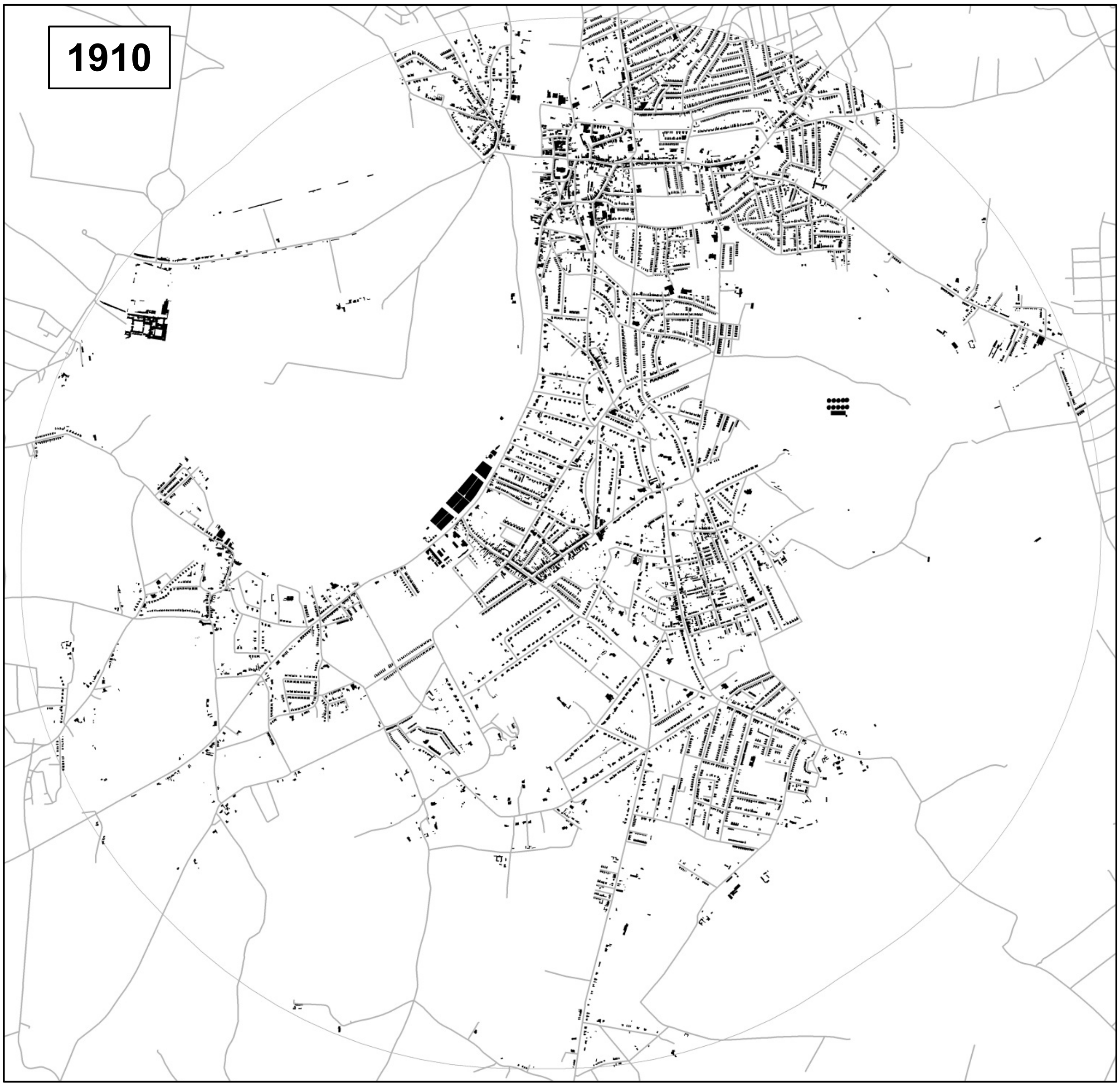


South Norwood Building Footprint Reconstruction and Historic Street Network

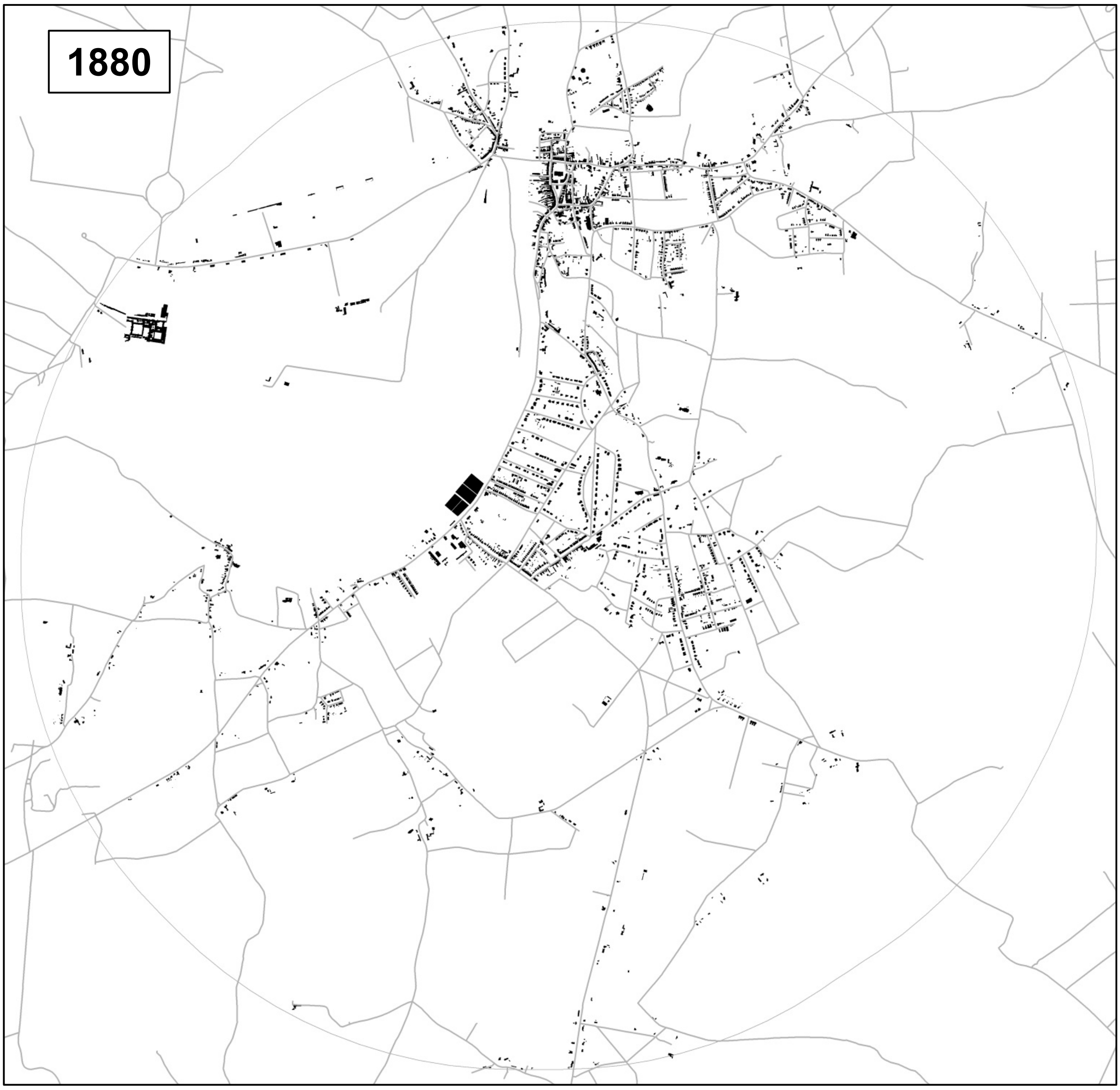
South Norwood Building Footprint Reconstruction and Historic Street Network

South Norwood Building Footprint Reconstruction and Historic Street Network

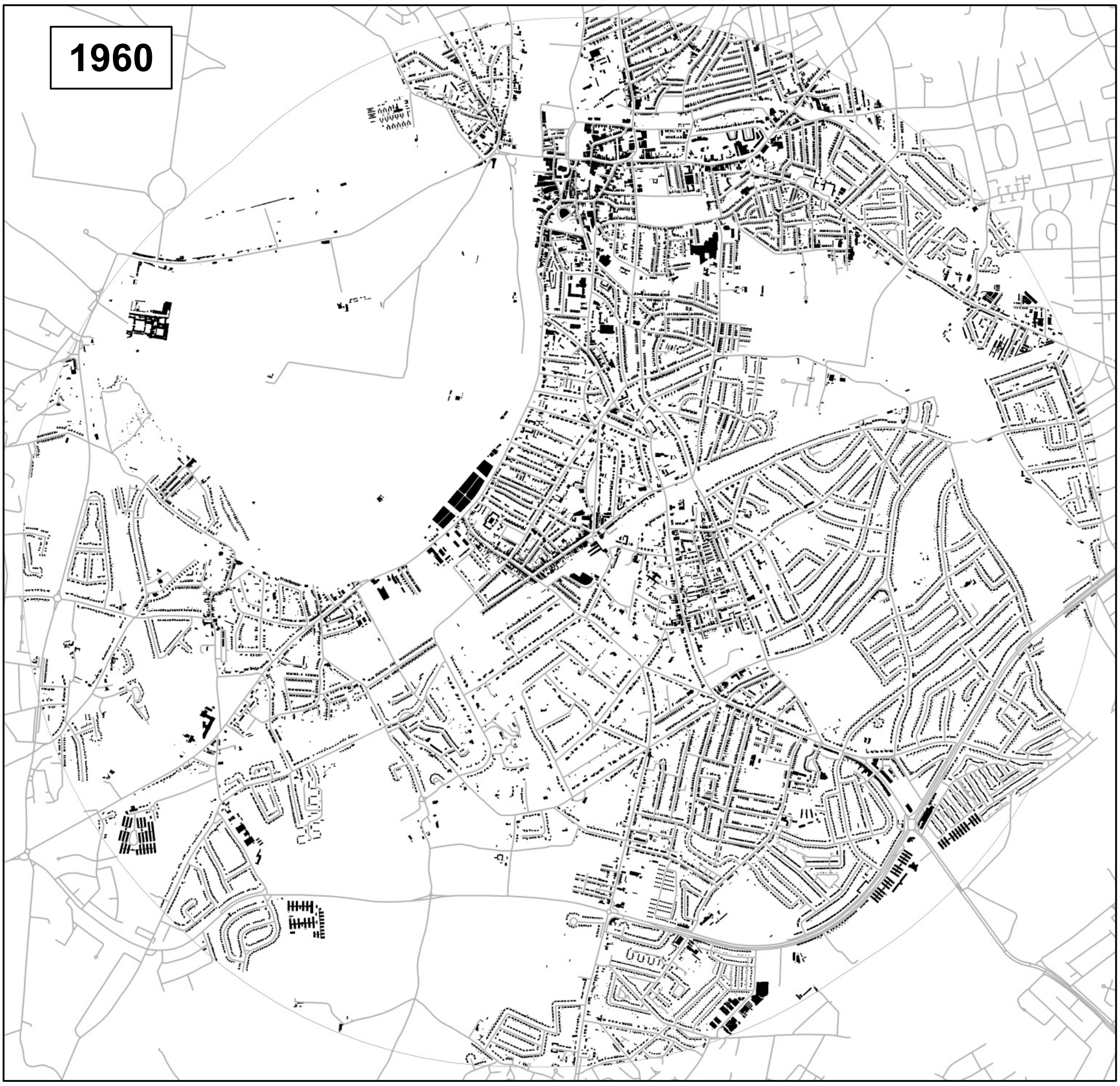
Surbiton Building Footprint Reconstruction and Historic Street Network



Surbiton Building Footprint Reconstruction and Historic Street Network



Surbiton Building Footprint Reconstruction and Historic Street Network



Surbiton Building Footprint Reconstruction and Historic Street Network